AD 273 749

PROJECT LIGHTNING

Third Phase

FIFTH QUARTERLY PROGRESS REPORT

VOLUME II

NObsr 77521

REMINGTON RAND
UNIVAC
DIVISION OF SPERRY RAND CORPORATION

PROJECT LIGHTNING
THIRD PHASE
NObsr 77521

FIFTH
QUARTERLY REPORT
VOLUME II

This report covers the period from
1 June 1961 to 31 August 1961

PX 1599-5

Remington Rand Univac®
DIVISION OF SPERRY RAND CORPORATION
UNIVAC PARK, ST. PAUL 16, MINNESOTA

INTRODUCTION

Project Lightning was established at the Sperry Rand Corporation in June, 1957, under Contract NObsr 72728. This project has performed research to indicate the feasibility of and to serve as the basis for the evolution of an ultrahigh-speed data-processing system. Several divisions of the Corporation have carried out the project work in geographically separated laboratories to make the best use of personnel and facilities.

For some time prior to this Contract,the St. Paul Laboratory had been investigating the possibility of using vacuum-deposited uniaxially-anisotropic ferromagnetic film elements for the development of computer components. Project Lightning has continued this work, emphasizing the development of rapid-access memories and arrays of film-core elements whose states may be switched rapidly at low power for logical operations.

In the Third Phase of Project Lightning, beginning in June, 1960, Remington Rand Univac proposed to design, construct, and test a Lightning Test Machine. This machine is expected to demonstrate the feasibility of operating magnetic film search memories and shift matrices under controlled conditions so that their capability may be evaluated. Remington Rand Univac also proposed to continue research efforts to improve the preparation of magnetic film elements and the measurement of their properties. Also to be continued is investigation of the application of magnetic film elements in search memories and shift matrices as well as in other devices which might also contribute to the development of ultrahigh-speed data-processors. Mathematical and logical research will continue, particularly with respect to majority-decision logic and systems organization.

CONTENTS

CONTENTS (CONT.)

ILLUSTRATIONS

ILLUSTRATIONS (CONT.)

ABSTRACT

1. FILM CORE MEMORY

a. FILM DEPOSITION TECHNIQUES. An improved method of producing nickel-phosphorous substrates for electroplated permalloy has resulted in substrates with superior surface properties.

Various substrate materials have been compared on the basis of the magnetic properties of the permalloy film elements deposited by evaporation onto the substrates. Comparisons were made over a range of residual pressures and with the addition of oxygen during deposition.

Vycor* heaters arranged with proper geometry have given good substrate temperature uniformity over the substrate area used for deposition. A study will be made of the substrate temperature in the film area during deposition, and efforts will be made to correct temperature deviations from the normal.

Concentrated sources and ring sources are being studied. A thickness-monitoring geometry has indicated a ring source nonuniformity which will be corrected.

Preliminary results with the omegatron residual gas analyzer are similar to the results published by others. Because the analysis of the mass spectrum obtained is in many cases ambiguous, additional experimental data are required to identify the gas components.

Work is being continued on the effects that the rate of deposition has on the magnetic parameters of the films produced. The high-vacuum ion bombardment is also being continued under more desirable operating conditions.

b. APPARATUS AND INSTRUMENTATION. The high-temperature anneal furnace has been placed in operation and functions as expected. The omegatron gas analyzer is also in operation, but as yet displays an excess of background noise.

* "Vycor" is a registered trademark of Corning Glass Works.

Automation of the deposition process is being planned. Rate and thickness of deposition will be controlled by feedback from the crystal monitor, and substrate temperature will be regulated to maintain as nearly as possible a constant temperature during deposition.

c. FILM PROPERTY MEASUREMENTS. The anisotropy field, H_K, and coercive force, H_C, were measured for 4-mm diameter permalloy film elements deposited at a vacuum pressure of about 10^{-6} torr on eight different types of glass substrates supplied by Corning Glass Works. The particular type of glass used as a substrate for deposition of permalloy film elements under the vacuum deposition conditions was found to have no significant effect on the range and average values of the coercive force and anisotropy field within the error of measurement of these parameters on the 1000-cycle hysteresis loop checker; i.e., $\pm$ 5 percent. The results show that the soda lime, borosilicate, micro-optical, lead, and control microslide glass substrates yielded the lowest average values of H_C for the 120 permalloy film elements checked for each of the different types of glass substrates.

When permalloy films were vacuum-deposited from a melt of 83 percent nickel and 17 percent iron onto glass substrates at temperatures ranging from 450 C to 200 C, the anisotropy field, H_K, was found to vary from less than 2 oe to 9 oe, and dispersion measurements of the "easy" axis were found to vary from 20° to less than 2°.

Composition gradient studies are being continued. Difficulties in finding the variation in composition have been encountered, and other means to obtain the gradient have been proposed.

d. SWITCHING AND RESONANCE STUDIES

(1) FILM SWITCHING STUDIES. In an effort to correlate switching behavior to "easy" axis dispersion measurements, switching data have been obtained for a few film samples with dispersion angles of less than 1°. However, any conclusions from these data may have to be changed after larger samplings. Meanwhile, dispersion measurements of samples previously checked in the switching apparatus have continued throughout the report period.

(2) FERROMAGNETIC RESONANCE STUDIES. To extend ferromagnetic resonance measurements to higher frequencies and to reduce bothersome transients present in the output signal of the film, several modifications have been made in the apparatus. These transient phenomena, as yet unexplained, will bear further investigation.

e. APPLICATIONS

(1) THICKNESS MEASUREMENTS. Thickness measurements were made using a Taylor-Hobson Model 3 Talysurf surface-measuring instrument having a reported accuracy of $\pm$ 200 A. Measurements were made on 1/4-mil Mylar, mica film substrates, and 1/2-mil copper strip lines lai on Mylar.

(2) SHIFT MATRIX. A new mode of operation for the 24 x 24 shift matrix which does not require a d-c bias is discussed. Single films and film pairs 0.050 inch in diameter were tested. A new circuit was fabricated with total thickness of 0.0014 inch which allows a 70-percent increase in the signal output due to the second film. Tests were also made on a 4 x 4 etched circuit array.

(3) HIGH DENSITY STORAGE. High-density bit storage has been found to be coincident with high-speed memory operation. Investigations have shown that a bit may be defined by an area determined by the applied field. This approach allows a selection of individual bits along a strip of permalloy 1 mm x 1 cm. Bit storage of 50 per inch and 100 per inch was observed with a Kerr magneto-optic apparatus.

(4) TUNNEL DIODE PERMALLOY FILM DRIVERS. Work has been done on tunnel diode driven permalloy films using thin drive lines of various widths. Drive strips of 1000 A to 3000 A thickness were used with tunnel diode drivers having a 100-ma peak current and producing a 60- to 70-ma drive current with a rise time of 1.5 to 2.0 nsec. Circuits have been built with the intention of using film outputs to trigger a tunnel diode detector which gives a relatively high voltage output, which in turn triggers a high current diode for a rewrite pulse.

2. MATHEMATICS AND LOGIC RESEARCH

The general-purpose logic array, the majority-logic comparator, and the majority fundamental theorem have all been generalized or otherwise improved and a majority-to-minority conversion theorem is given.

3. LIGHTNING TEST MACHINE

a. HIGH-SPEED MEMORY STACK DESIGN. A number of strip film core arrays (22 mils wide by 16 film elements long) were made during this period, both by evaporation through mask and etching from sheet films (mirrors). Coupled 20-mil strips typically produced 2-mv peak sense signals (approximately twice that of round spots), using 0.4- to 0.5-amp word currents, rising in 15 to 20 μsec. Switching speeds of the strips were at

least as good as those obtained from round spots. Strip cores etched from continuous sheets appear to perform equally well. A 128-word, 24-bit word search memory using 35-mil BICORE film elements is in progress. The proposed Project Lightning thin film shift matrix will shift a 24-digit word up to 23 places in a cycle time of 100 nsec. For this shift matrix three 4 x 4 test arrays have been designed and tested. An array tester for LTM planes and film core arrays is being designed and a 4 x 4 prototype is being constructed.

b. SENSE AMPLIFIER. An amplifier has been built to provide 1) difference signal detection and amplification; 2) Class A, wide-band amplification of both channels; 3) tunnel diode low-level gating, with a current-steering strobe control; and 4) output amplifiers for both channels that provide a signal compatible with the logic circuits. The amplifier has good stability and should allow a 50-nsec memory cycle time if other delay factors in the loop can be reduced. The amplifier when packaged can be plugged into the JDU for checkout. After testing and some modification, the amplifier should be usable in the LTM.

c. HIGH-LEVEL WORD TRANSLATION. Further work has been done on high-level word current translation. Lumped section transmission lines have been dropped, in favor of distributed lines of higher characteristic impedance.

d. FILM STRIPS. Film strips and slit film strips were evaluated for deterioration due to cross coupling in an effort to determine whether this deterioration was detrimental to the reliable operation of film strips as memory elements in the high-speed memory. The investigations show that although further testing in a larger memory array is required, the slit strips should operate reliably.

e. REPRODUCIBILITY OF ELECTROPLATED THIN FILMS. UEC, Philadelphia, studied the preparation of 20-mil Ni-Fe electroplated film spots with reproducible properties. Although too few spots were measured to yield conclusive information on reproducibility, the three 32 x 24 arrays tested operated in a normal manner compared to vacuum-deposited spots. There are positive indications that any electrodeposited films that give good reproducibility for 50-mil diameter circular spots, or any other shapes, will also be adequate for smaller sizes and shapes. Appropriate configurations and thickness would have to be used.

DETAILED DATA

1. FILM CORE PROGRAM

a. FILM DEPOSITION TECHNIQUES

(1) SUBSTRATES FOR ELECTROPLATED PERMALLOY. The major work on electroplated films during the last quarter has been concerned with producing uniform nickel-phosphorous substrates.

Improvements have been made in the method for producing nickel-phosphorous substrates, resulting in unstained surfaces with uniformly better smoothness as indicated by Talysurf[1] measurements. It has been found that vapor-blasting the border of the glass slide results in improved adhesion of the electroless nickel so that no solution leaks between the glass and nickel during subsequent copper plating. Such leakage was a major source of difficulty in the substrates produced earlier. Other changes involved substitution of a sulfuric-chromic acid cleaning treatment of the glass for the hot alkaline cleaner previously used. This change was made to minimize the possibility of roughening the glass surface by the cleaning technique. Adjustments were also made in the palladium chloride activator solution.

A holder for the glass slides is being constructed to simplify handling and minimize damage during plating operations.

Because substantially improved substrates are now being obtained, it is expected that examination by electron microscopy of surface replicas will be facilitated, and that such examination will aid in developing improved substrate surfaces. It is also expected that plating of permalloy films for the evaluation of magnetic properties will be resumed shortly.

(2) SUBSTRATE TEMPERATURE MEASUREMENT. The Vycor heater mentioned in the preceding report has been investigated further. It was found that by suitably adjusting the geometry of the heater elements and their reflectors, substrate temperature

---

1. "Talysurf" is a registered trademark of Taylor, Taylor, and Hobson, Ltd.

variations could be reduced to 5 C. Unfortunately, each such heater array may have to be experimentally adjusted to give such uniformity. However, this type of heater appears to be capable of better uniformity than the wire grid formerly used.

(3) SUBSTRATE COMPARISONS. Glass microslides, cleaved mica, quartz, and vacuum-deposited copper (electroplated and peeled from a glass substrate) have all been utilized as substrate materials in the vacuum deposition of permalloy film cores (83 percent nickel and 17 percent iron). The depositions were performed in a vacuum system capable of achieving an ultimate pressure of 10^{-9} torr. Peak pressures during evaporation ranged from 10^{-5} to 10^{-8} torr. Upon evaluating the resulting film characteristics, it was found that glass microslides afforded the lowest average coercive force, the lowest variation in coercive force and anisotropy field, and the smallest variation in "easy" axis angles. Average anisotropy field of films deposited on quartz was 0.1 oe lower than for glass.

(a) SUBSTRATE COMPARISON WITH ADDITION OF OXYGEN. A similar comparative study of substrate materials has been made, the only difference being that oxygen was added during evaporation by means of thermal decomposition of peroxides within the vacuum chamber (Table 1).

TABLE 1. SUBSTRATE COMPARISON WITH ADDITION OF OXYGEN

	Average H_C (oe)	Average Range of H_C (oe)	Average H_K (oe)	Average Range of H_K (oe)	No. of Evaporations
Glass	2.2	0.5	3.6	1.0	18 (144 bits)
Glass + O_2	1.9	0.4	3.6	0.6	9 (72 bits)
Mica	2.9	1.4	5.5	2.8	5 (40 bits)
Mica + O_2	2.3	0.9	5.5	1.9	6 (48 bits)
Quartz	2.7	0.5	3.5	0.9	5 (40 bits)
Quartz + O_2	2.7	0.3	4.3	0.6	4 (32 bits)

From the limited data obtained thus far, it appears that average values of coercive force and anisotropy field were not appreciably affected by the addition of oxygen, but the ranges of values of these characteristics were decreased for glass, mica, and quartz. In six out of seven depositions on copper, the resulting films were "stiff" (would not display a hysteresis loop) when oxygen was added.

For each evaporation in which oxygen was added, pressure was increased from 3×10^{-8} to 1×10^{-6} torr prior to the actual fusing of the permalloy. This elevated pressure was maintained for 30 to 60 seconds prior to, during, and for 30 to 60 seconds after evaporation of the permalloy.

Further studies of the results of adding various gases in the process of depositing permalloy film cores will be continued.

(4) PROPOSED SUBSTRATE TEMPERATURE STUDIES. A study will be made to determine the substrate temperature in the film element area during deposition, using deposited thermocouples as the sensing elements. This temperature will be a function of evaporation rate, source configuration, substrate heater power, and heat dissipation. Efforts will be made to correct detected temperature deviations from the normal, using power balancing between the substrate heater and the source. A theoretical and experimental study also will be made to determine the substrate temperature distribution due to radiation from the ring source.

(5) SOURCE STUDIES. The wire feed source[2] has operated reliably and fulfills quite well the requirements of a concentrated, continuously operable source with little fractionation. This source will be particularly useful in conjunction with a substrate changing apparatus. This source is more desirable than a ring source for small film element deposition through a mask, as the shadowing problem is minimized.

It is anticipated that another concentrated source will be evaluated. This source is the electron beam bombardment heating of a free-standing permalloy post.

A crystal thickness monitor mounted within a single solid tungsten wire ring source, and exposed to a small part of the ring, has given erratic thickness results. This indicates that the ring source is nonuniform, and that methods of correcting the nonuniformity are necessary. One filament configuration now in use eliminates the formation of molten globules and is therefore quite likely a more uniform ring source. It consists of a large single wire, around which is helically wound a fine tungsten wire. A twisted filament would very likely do equally well.

(6) RESIDUAL GAS ANALYSIS. During this report period, the omegatron mass spectrometer was installed in the NRC coater and placed into operation. A block diagram of the mass spectrometer is shown in Figure 1. The omegatron tube was constructed by Leybold's Nachfolger and was purchased from the National Research Corporation. The

---

2. Fourth Quarterly Progress Report, Project Lightning, Phase III, Vol. II.

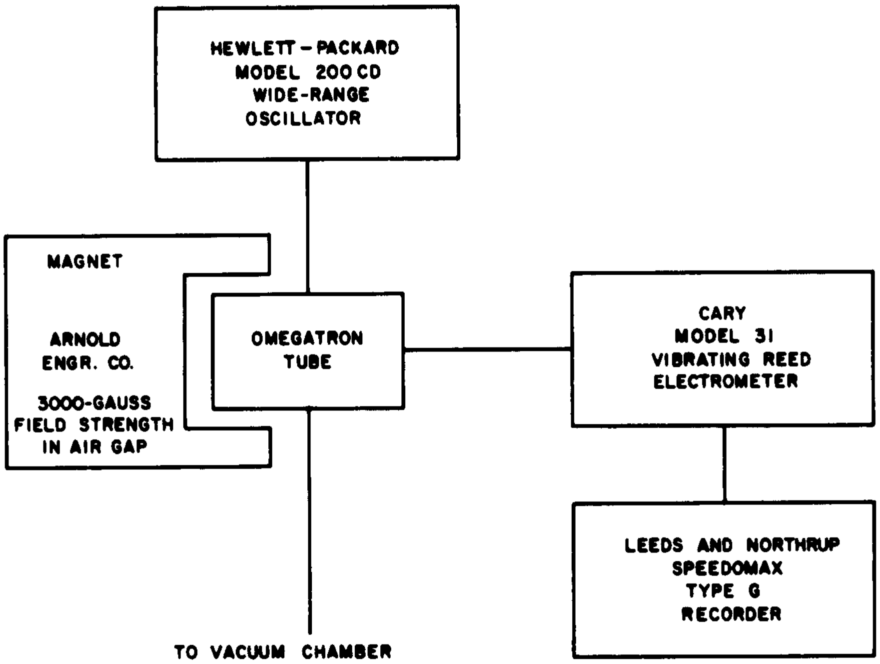


Figure 1. Omegatron System

axial magnetic field is supplied by a permanent magnet which produces a 3000-gauss induction across an air gap of 1-1/4 inches. The ion current is measured with a Cary Model 31 vibrating-reed electrometer, and the output spectrum is displayed on a Leeds and Northrup chart record.

A major problem has been encountered in attempting to eliminate spurious currents appearing in the spectrum. The electrometer has proved to be a reasonably stable instrument except for an occasional period of unexplained drift. A major source of noise was found in the leads from the ion collector to the electrometer head. A rigid mounting for the head, shielding, and a rigid coaxial connection have improved the signal-to-noise ratio considerably. The major remaining source of spurious currents seems to reside in the omegatron itself.

Figure 2 is a chart recording of a portion of the spectrum made while the vacuum system metal parts were at room temperature. The principal peaks are located at mass/charge ratios of 28 and 32, representing singly ionized nitrogen and carbon monoxide, and singly ionized oxygen, respectively. The triple peaks at 32 have not been explained and,

in fact, have been observed but once, indicating a possible transient instrumentation error. The broad peaks at 57 and 69 mass/charge ratios have been observed by Lichtman[3] and called by him "alcohol fractions" which remained in the chamber from previous experiments. Caswell[4] studied the outgassing of gasket materials and claimed that the peaks he obtained at mass/charge of 56 to 58 and 70 to 72 were butane (C_4H_{10}) and pentane (C_5H_{12}), respectively. However, in preparing his gasket material samples, he used an alcohol (not identified) rinse. Since Lichtman's apparatus was all-metal, using knife-edge metal seals, his "alcohol fraction" hypothesis would appear to gain support. These peaks (at 57 and 70) appear consistently in the system used on Project Lightning and in one case, the partial pressure of the mass/charge 57 fraction became greater during a mild bakeout.

Figure 3 is a typical spectrum of the residual gas immediately following film deposition. It is evident that the higher chamber pressure during deposition has introduced spurious ion currents in the spectrometer. An operating characteristic of this particular spectrometer tube is that the upper limit of chamber pressure which can be tolerated is 2 to 5 x 10^{-5} torr. Since the chamber pressure rises to this range during deposition, the limits on mass resolution are being penetrated and the usefulness of the instrument impaired. However, useful information can be gained concerning evolution of gas from the various system parts during bakeout and from a study of the gas composition during an extended pumping period. The study of gas evolved during actual film deposition may require postponement until the omegatron can be installed in an ultra-high vacuum system.

(7) RATE OF DEPOSITION STUDIES. A new series of evaporations is under way to recheck the influence of the rate of deposition on dispersion and other magnetic film parameters. The previous study[5] was performed under adverse conditions, and the variations in the magnetic parameters for reasons other than rate overshadowed the effects of rate of deposition. This deposition parameter appears to be quite important and warrants a further study under more desirable operation conditions.

(8) ION BOMBARDMENT TECHNIQUES. The study proposed[6] and initiated on high-vacuum ion bombardment for substrate cleaning and for film treatment during and after deposition will be continued. The program begun in the past quarter shared the difficulties of generally poor films with the rate of deposition experiments, both of which

---

3. *J. Appl. Phys.*, 31, 1213 (1960).
4. *IBM Journal*, 4, 130 (April, 1960).
5. Third Quarterly Progress Report, Project Lightning, Phase III, Vol. II.
6. Ibid.

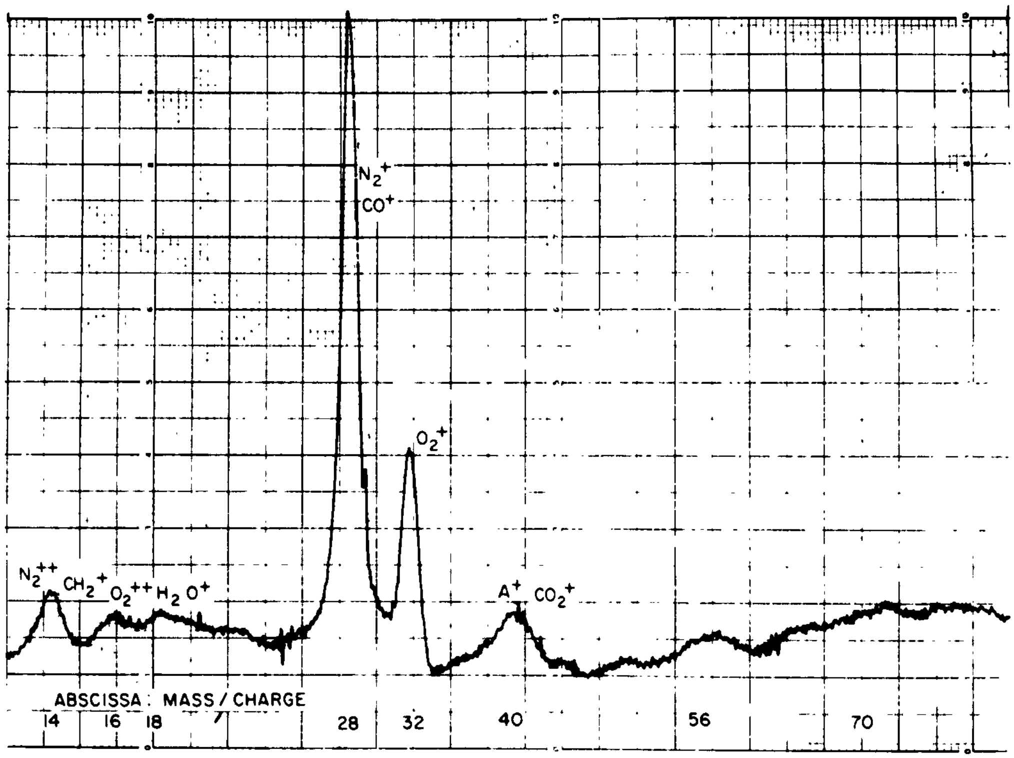


Figure 2. Spectrum Recording of Vacuum System Metal Parts at Room Temperature

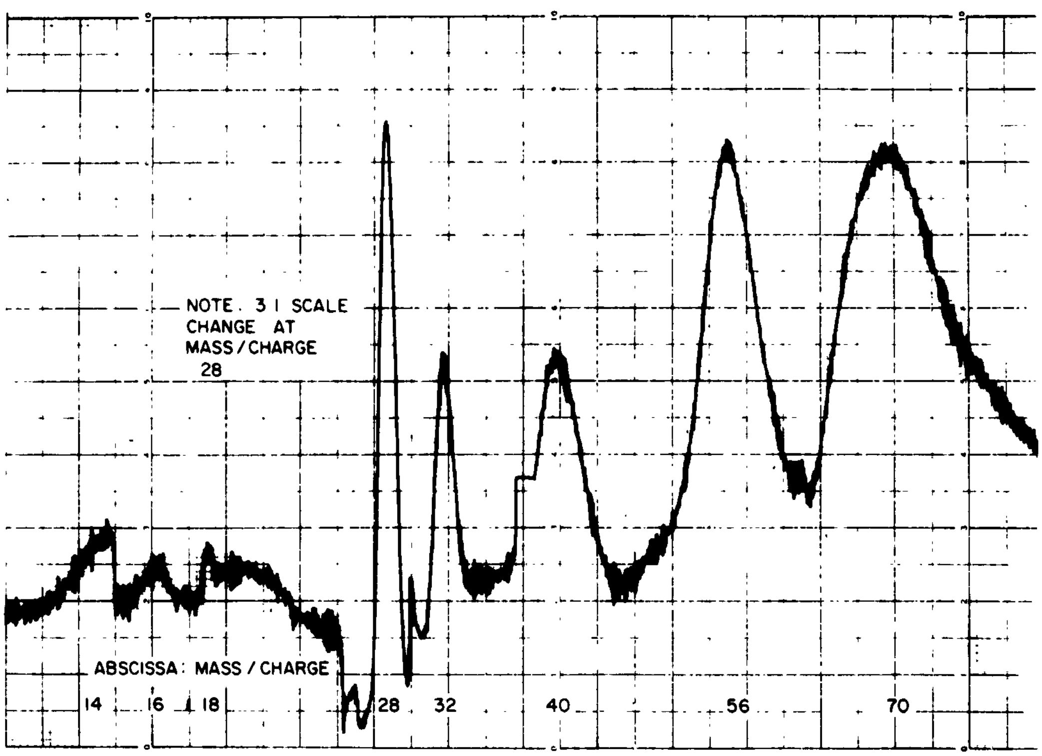


Figure 3. Typical Spectrum of Residual Gas Immediately After Film Deposition

were performed in the Evapor-Ion[7] pump system which suffered from a now corrected defect. The results with argon as the bombarding gas did indicate, however, a beneficial uniformity improvement in magnetic parameters.

(9) ULTRA-LOW PRESSURE EFFECTS. Vacuum deposition of 83-17 permalloy film cores has been carried out at peak pressures in the 10^{-8} torr range. Resulting film characteristics were not appreciably different from those of films deposited at 10^{-5} to 10^{-6} torr in the same vacuum system under otherwise identical conditions. Further analysis of ultralow pressure effects will be continued.

b. APPARATUS AND INSTRUMENTATION

(1) ANNEALING FURNACE. The annealing furnace described in the last report[8] has been placed in operation. Argon and hydrogen will be used for high-temperature anneal and diffusion studies of permalloy films. High-temperature bakeout of glass substrates will also be done in this system.

(2) OMEGATRON GAS ANALYZER. The omegatron mass spectrometer which has been described in detail under film deposition techniques will be a valuable tool in correlating film properties with residual gas content.

(3) DEPOSITION AUTOMATION. A rate of deposition control employing the mechanical rate monitor is being devised. An electrical output device attached to the rate monitor shaft will feed back signal to the source power supply for constant rate of deposition control. The system will also terminate the evaporation at a predetermined thickness. A multicontact meter relay or a saturable reactor will control a percentage of the total power supplied to the evaporation source.

(4) SUBSTRATE TEMPERATURE CONTROL. The construction of an automatic substrate temperature control unit is contemplated and will be based on the information gathered from the film element temperature study discussed under Film Deposition Techniques. A programmed control along with a thermocouple sensing element will regulate the power to the substrate heater. In addition to better temperature regulation, this unit will eliminate a large amount of operator time.

---

7. "Evapor-Ion" is a registered trademark of Consolidated Electrodynamics, Inc.
8. Fourth Quarterly Progress Report, Project Lightning, Phase III, Vol. II.

c. FILM PROPERTY MEASUREMENTS

(1) MAGNETIC PROPERTIES OF PERMALLOY FILM ELEMENTS DEPOSITED ON SELECTED CORNING GLASS SUBSTRATES. Comparative studies of different types of glass as substrates were made by simultaneously vacuum-depositing film elements on a number of different glass samples supplied by Corning Glass Works. Conventional microslide glass normally used here was the control. The vacuum chamber, specific evaporation techniques, testing facilities, and procedures were those used in the glass-cleaning studies.

The 1 x 1.5-inch experimental glass and the microslide glass substrates varied in thickness from 1.0 to 1.4 mm. The sample glass substrates and the control slide were chalk-cleaned. Twelve 4-mm diameter permalloy film elements were deposited onto each of the glass samples and onto the control slide. Each of these 12 film elements was checked in the 1000-cycle hysteresis loop checker. The magnetoelastic strain coefficient η varied from +0.3 to +0.6; the saturation flux, ϕ_S, varied from 0.045 to 0.060; and the anisotropy field, θ, varied from 170° to 185° for the 1200 permalloy film elements checked. Table 2 shows the results for 10 evaporations of each of the first 4 different types of glass and the standard microslide glass control. The soda lime microslide glass was used as a control, and the values of H_C for the Corning soda lime and the microslide were identical. The lead glass shows a lower average value of H_C for the 10 evaporations; i.e., a total of 120 permalloy film elements. However, the resulting average values for H_C and H_K are within limits of reliability of the 1000-cycle hysteresis loop checker ($\pm$5 percent).

Table 3 shows the secondary set of evaporations in which the copper sealing glass substrate yielded a higher value of H_C. The borosilicate glass substrates yielded lowest values of H_C.

Table 4 shows the measured angular dispersion $\alpha\, 90$[9] of the "easy" axis as measured by the crossed field hysteresis loop checker and the coefficients of expansions for the various types of glass substrates. The data shown for the different types of glass are all within the reproducibility of the testing techniques.

From the preceding data, it can be seen that coefficient of expansion and the chemical composition of the glass have either no effect or an effect too small to be determined by current testing techniques, if the substrates are all cleaned and deposited in the same

9. The angle for which 90 percent of the maximum remanent flux is picked up (Sixth Quarterly Progress Report, Project Lightning, Phase II).

TABLE 2. MAGNETIC PARAMETERS OF VACUUM-DEPOSITED PERMALLOY ON SELECTED CORNING GLASS SUBSTRATES

Type of Glass	Glass No.	Average Value of 12 Elements										Average Value of 10 Evaporations
					Coercive Force H_C (oe)							
Soda Lime	0087	1.8	1.9	1.4	1.6	1.5	1.7	1.4	1.4	1.6	1.6	1.59
Copper Stain	7740	2.8	2.5	1.9	1.6	2.0	2.0	1.7	2.0	2.1	1.9	2.05
Micro-optical	0211	2.2	1.5	1.8	1.6	1.6	1.6	1.3	1.5	1.7	1.5	1.63
Lead	9160	1.7	1.5	1.5	1.5	1.5	1.6	1.3	1.3	1.4	1.6	1.49
Microslide		1.7	1.6	1.5	1.4	1.6	1.6	1.5	1.6	1.7	1.5	1.57
					Anisotropy Field H_K (oe)							
Soda Lime	0087	4.1	3.4	2.8	3.1	3.0	2.9	3.3	3.5	2.8	3.1	3.20
Copper Stain	7740	4.0	3.4	3.0	3.1	3.1	3.1	3.2	3.3	2.8	2.9	3.19
Micro-optical	0211	4.2	3.0	2.9	3.0	2.9	3.0	3.1	3.4	2.8	3.0	3.13
Lead	9160	4.3	2.9	2.7	2.9	2.9	2.9	3.2	3.4	2.5	3.1	3.08
Microslide		4.6	3.1	2.7	2.9	2.8	2.7	3.2	3.2	2.7	2.9	3.08

TABLE 3. MAGNETIC PARAMETERS OF VACUUM-DEPOSITED PERMALLOY ON SELECTED CORNING GLASS SUBSTRATES

Coercive Force
H_C (oe)

Type of Glass	Glass No.	Average Value of 12 Elements										Average Value of 10 Evaporations
Alkali-free	7059	1.7	1.9	1.4	1.6	1.4	1.4	1.7	1.3	1.5	1.6	1.55
Kovar Sealing	7056	1.5	1.4	1.4	2.0	1.5	1.4	1.7	1.4	1.7	1.6	1.56
Copper Sealing	7295	1.7	1.9	2.0	1.9	1.5	2.3	1.9	1.5	1.5	2.4	1.86
Borosilicate	7740	1.6	1.3	1.5	1.3	1.3	1.5	1.7	1.2	1.4	1.1	1.39
Microslide		1.7	1.5	1.5	1.4	1.3	1.3	1.7	1.5	1.4	1.4	1.46

TABLE 3. MAGNETIC PARAMETERS OF VACUUM-DEPOSITED PERMALLOY ON SELECTED CORNING GLASS SUBSTRATES (Cont.)

Anisotropy Field H_K (oe)

Type of Glass	Glass No.	Average Value of 12 Elements										Average Value of 10 Evaporations
Alkali-free	7059	2.8	3.4	3.2	2.9	3.0	2.5	3.0	3.1	3.2	3.7	3.08
Kovar Sealing	7056	2.9	3.1	3.1	3.0	3.0	3.0	3.2	3.1	3.3	3.5	3.12
Copper Sealing	7295	2.8	3.0	3.0	2.8	2.5	3.0	3.0	3.4	3.4	3.3	3.00
Borosilicate	7740	5.0	3.1	3.0	3.0	3.1	2.7	3.2	3.2	3.2	3.6	3.11
Microslide		2.8	3.1	3.0	2.9	2.6	2.5	3.2	3.0	3.3	3.4	2.99

TABLE 4. ANGULAR DISPERSION OF VACUUM-DEPOSITED PERMALLOY ON SELECTED CORNING GLASS SUBSTRATES*

Series I

Type of Glass	Glass No.	Coefficient of Expansion	Angular Dispersion (Degrees)
Soda Lime	0087	101×10^{-7}	4.4
Copper Stain		150×10^{-7}	5.7
Micro-Optical		72×10^{-7}	4.5
Lead		97×10^{-7}	5.0
Microslide			4.5

Series II

Type of Glass	Glass No.	Coefficient of Expansion	Angular Dispersion (Degrees)
Alkali-free		47×10^{-7}	4.4
Kovar Sealing		51×10^{-7}	4.3
Copper Sealing		150×10^{-7}	7.0
Borosilicate			4.1
Microslide			3.7

*Average value for three 8-mm film elements per evaporation with a total of 10 evaporations.

manner. (However, Corning Glass Works is cooperating with Project Lightning, and experimental work on glass substrates and their effect on magnetic properties of permalloy film elements will be continued.)

(2) MAGNETIC PROPERTIES OF PERMALLOY FILM ELEMENTS AS A FUNCTION OF DEPOSITION SUBSTRATE TEMPERATURE. A series of experimental evaporations has been made to determine the magnitude of the effect that substrate deposition temperatures have on the anisotropy field, H_K. The 1600-A, 4-mm diameter, uniaxial permalloy film elements were vacuum deposited onto microslide glass substrates utilizing the vacuum techniques and procedures of the glass cleaning studies.[10] The glass substrates were chalk-cleaned and heated by a radiation Vycor substrate heater[11] in the vacuum coater for 2 hours at 300 C. The temperature measurements were made by a thermocouple junction cemented to a microslide glass substrate.[12] The substrate deposition temperature was then varied from 200 C to 450 C. The anisotropy field, H_K, was found to vary from 9 oe to less than 2 oe at a temperature of 450 C. At temperatures less than 250 C the numerical value of H_K became large and erratic. Above 400 C the permalloy film elements were generally inverted, i.e., $H_C > H_K$. At 375 C, H_K reached an average value of 2.5 oe. Figure 4 shows the resulting magnetic parameters for a uniformity series of 20 consecutive evaporations at a substrate deposition temperature of 375 C. The points represent the average value for the coercive force, H_C, anisotropy field, H_K, the anisotropy axis, θ, and the saturation flux, ϕ_s, for six of the eighteen 4-mm diameter permalloy film elements on the glass substrate as checked by the 1000-cycle hysteresis loop checker. Also, the magnetoelastic strain coefficient, η, is measured for one permalloy film element. As shown by the graph, the average value of H_C, 1.5 $\pm$ 0.1 oe, was exceeded in 3 of the total 20 evaporations. H_K, 2.5 $\pm$ 0.2 oe, was exceeded in 4 of the 20 evaporations. Measurements of dispersion angle, α 90, as checked on the 1000-cycle crossed field hysteresis loop apparatus varied from less than 2° to greater than 20°. At substrate deposition temperatures greater than 325 C, α 90 became larger and reached values as high as 20° at 450 C. At temperatures from 325 C to 250 C, α 90 was minimized to values varying from 3° to less than 1°. At 375 C the average numerical value of α 90 was 4°. Future work will involve obtaining more measurements of the anisotropy field, H_K, the dispersion angle, α 90, and the substrate deposition temperature in order to correlate these values more accurately.

10. Third Quarterly Progress Report, Project Lightning, Phase III, Vol. II, pp. 9-10.
11. Fourth Quarterly Progress Report, Project Lightning, Phase III, Vol. II, p. 23.
12. Ibid.

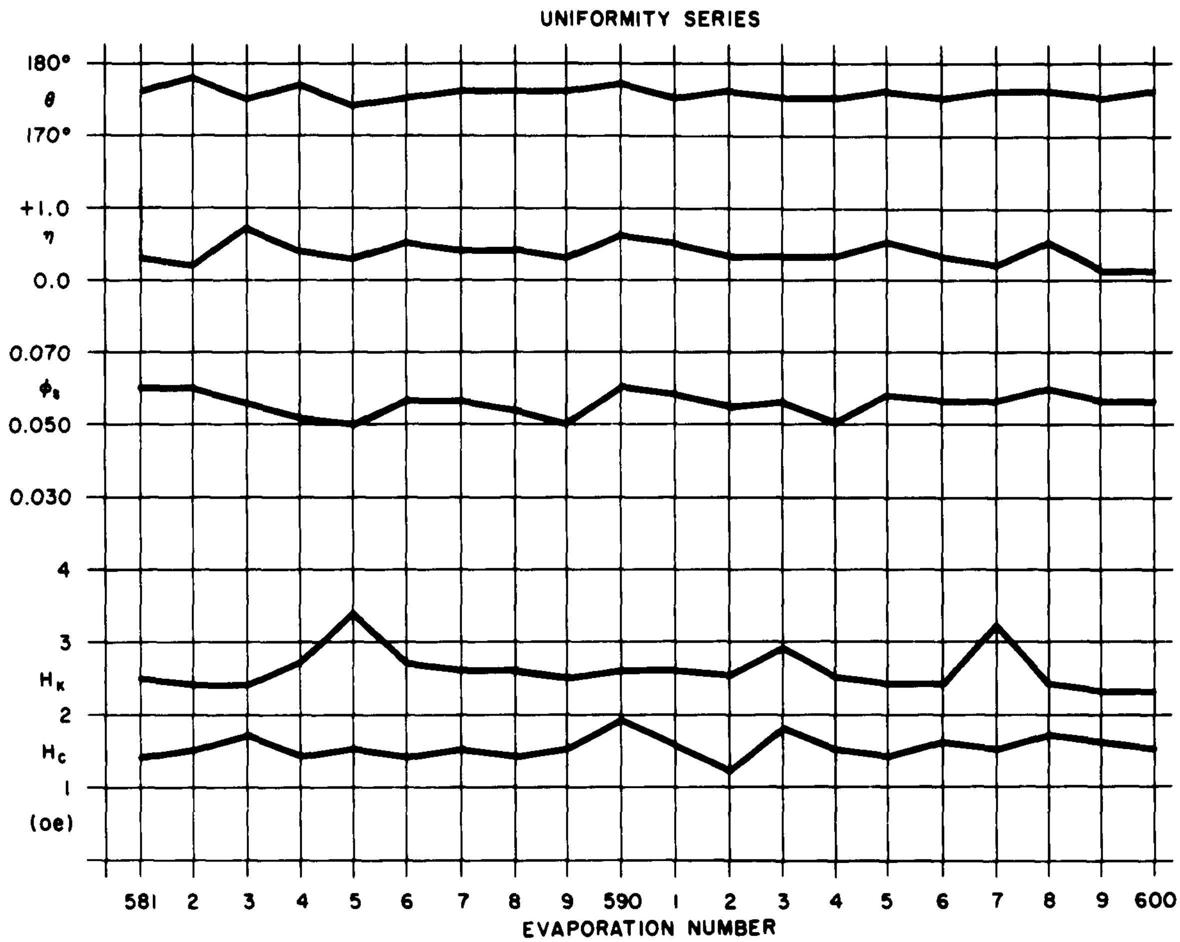


Figure 4. Magnetic Parameters for Uniformity Series

(3) COMPOSITION GRADIENT STUDIES. The composition gradient in permalloy films normal to the plane of the film is difficult to measure because of the thickness of the film. Several direct approaches have been or will be attempted, and several indirect approaches are feasible. Mechanical and also chemical etching and chemical analysis have been tried without success. A uniform mechanical etch to a thin layer was unsuccessful, and a nonpreferential chemical etch did etch preferentially and made the method unusable. Another method based on the thermal emf of permalloy as a function of composition will be investigated. The indirect approaches include 1) theoretical calculations in conjunction with split evaporations and subsequent analysis of each portion, and 2) alternate iron-nickel layer depositions from separate sources through a rotating mask

and subsequent diffusion at elevated temperatures. The rates of deposition and the frequency of rotation of the mask will determine the layer thicknesses. Magnetic properties will then be a function of layer thickness, total diffusion, and average composition.

d. SWITCHING AND RESONANCE STUDIES

(1) FILM SWITCHING STUDIES

(a) SWITCHING AND "DISPERSION" MEASUREMENTS. During this report period several film samples with measured dispersion angles of less than 1° became available for switching measurements. The samples were first switched in the solenoid apparatus and then in the strip line switching apparatus. The average slopes of these switching curves were determined from the solenoid switching curves for $H_T/H_K = 0.18$. These slopes were then plotted as a function of dispersion angle for 90 percent of remanence. This plot is shown in Figure 5 and includes all previous samples which have had average slopes and dispersion angles measured. The plot is similar to that of Figure 5 in Volume II of the last report[13] with more recent information included. In the last report it was indicated that steeper slopes tend to go along with smaller dispersion angles, but no information was available on samples with dispersion angles less than 1°. Figure 5 shows that this previous conclusion is not necessarily true, since at least one sample with a dispersion angle greater than 12° has a steeper slope than several samples with angles less than 1°. The trend in Figure 5 is still clear; steep slopes are *not* generally associated with large dispersion angles. In the future more samples having large dispersion angles will be checked to corroborate this statement.

Shown in Figure 6 are the switching curves of five different samples with dispersion angles less than 1°. These curves were extrapolated from the raw data so that $H_T/H_K =$ 0.18 for each curve. Three of the five curves show the second "knee" mentioned in the last report. The location of the "knee" or the lack of one does not seem to be easily related to H_K, but this small sampling is not to be regarded as conclusive. It has been observed from the raw curves that some samples exhibit not only a second "knee" but also a third "knee." At present there are not enough samples to indicate whether the third "knee" observed is due to film behavior or to instrumentation difficulties.

(b) SWITCHING INSTRUMENTATION. A voltage calibrator of the null-balance type was constructed to facilitate more accurate measurements of the longitudinal fields present in the solenoid switching apparatus. Field measurements can be made with

---

13. Fourth Quarterly Progress Report, Project Lightning, Phase III, p. 32.

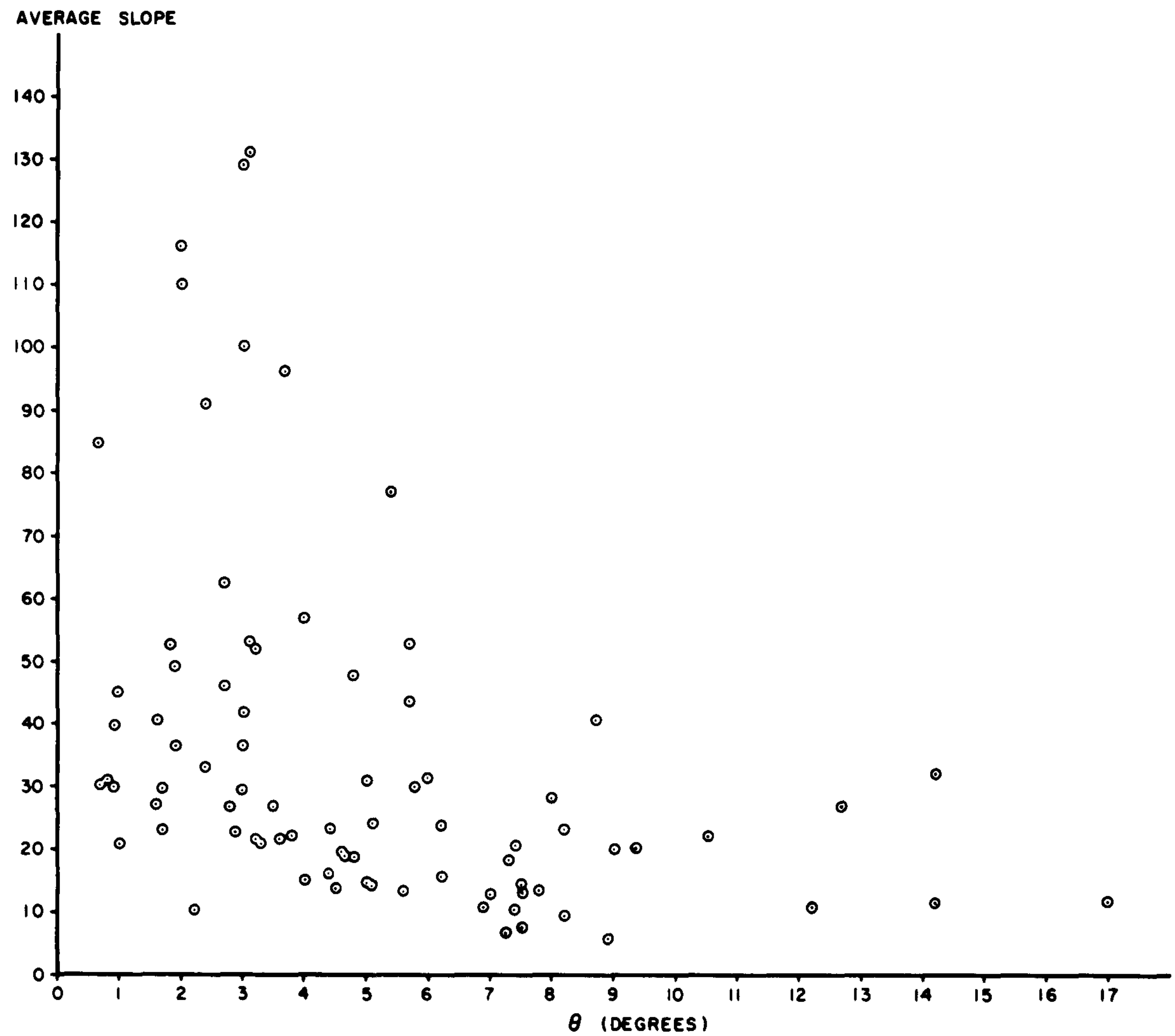


Figure 5. Average Slope *vs* Angle for 90 Percent of Remanence

an error of only 1 percent. To check switching time in samples with large dispersion angles, application of transverse fields on the order of $1/2H_K$ may be necessary. To provide these larger fields, a new cube coil and variable regulated voltage source have been constructed but not tested.

(2) FERROMAGNETIC RESONANCE STUDIES. During this period studies of ferromagnetic resonance in permalloy thin films have continued.

Further modifications and improvements are continuing to be incorporated into the apparatus. A cube coil capable of producing a larger field was constructed to effect more complete saturation of the films and to allow measurements at higher frequencies. It had

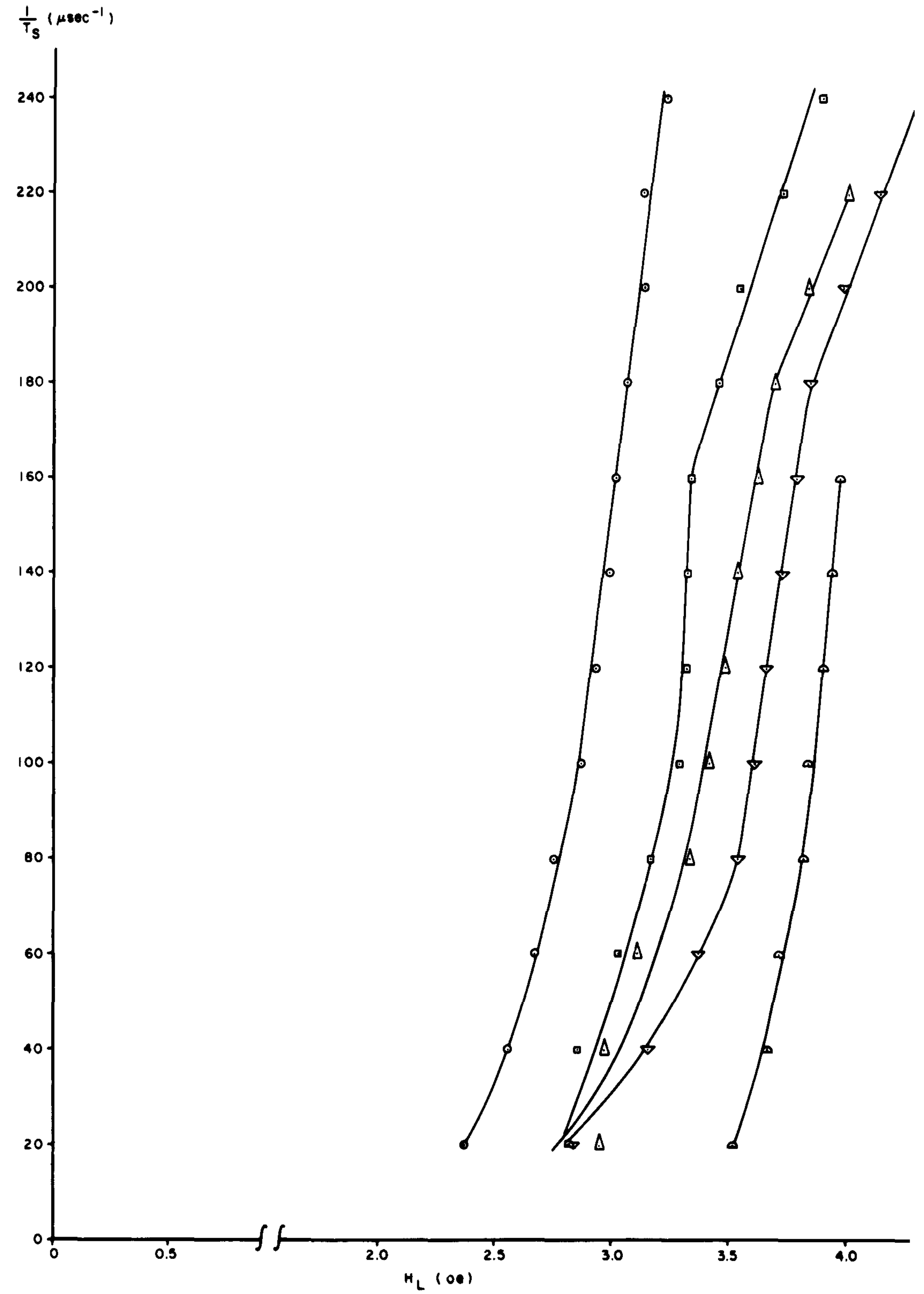


Figure 6. Fast Switching Curves for Five Different Samples with Less Than 1° Dispersion

been found that transients in the envelope of the UHF output signal occurred if the static magnetic field were varied at any rate other than very slowly. Although this effect is not now understood, some possible causes of it have been indicated. To alleviate the problem an automatic motorized controller has been built to vary the static field at a slow and uniform rate.

Consideration has been given during this report period to the possibility of extending the ferromagnetic resonance measurements into the X-band microwave region.

Results obtained during this period tend to corroborate those reported previously. This work has revealed several interesting, and as yet not understood, phenomena which will require further investigation.

e. APPLICATIONS

(1) THICKNESS MEASUREMENTS. A preliminary investigation of measured thickness of circuit materials used in the laboratory has been conducted.

A Taylor-Hobson Model 3 Talysurf surface-measuring instrument with a reported accuracy of ± 200 A was used to measure 1/4-mil Mylar[14], mica film substrates, and 1/2-mil copper strip lines laid on Mylar. In addition, a comparison was made between Krylon[15] and rubber cement when used as adhesives for multilayer circuits.

Specifications on the Talysurf give a stylus radius of 0.1 mil and a weight of 0.1 gram. This results in pressures over 7000 lbs/sq. in. It is possible that these pressures could seriously scratch the surface to be measured. Therefore, whenever possible the datum plane should be of the same material as the specimen. No difference was noted when the datum was changed from copper to Mylar.

The 1/2-mil copper measured 0.5 to 0.54 mil in thickness, the 1/4-mil Mylar, 0.25 mil, and five samples of mica varied from 0.3 mil to 1.4 mils. Rubber cement added between Mylar and the datum increased thickness 0.1 to 0.2 mil; Krylon increased thickness 0.05 to 0.2 mil.

Both Krylon and rubber cement cause the Mylar surface to become irregular, the worst case being that of the Krylon. It may be concluded that for laboratory experiments, while Krylon is capable of producing thinner adhesives, rubber cement is preferable because of its greater smoothness and consistency of thickness.

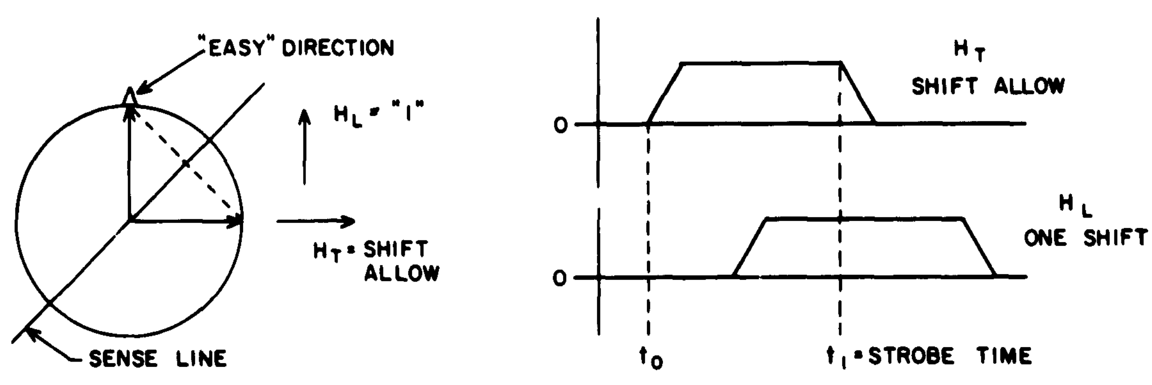
14. "Mylar" is a registered trademark of E. I. du Pont de Nemours and Company.
15. "Krylon" is a registered trademark of Krylon, Incorporated.

An investigation was made to see if the copper strip lines laid on Mylar are imbedded in the Mylar. A strip line measuring 0.5 mil was peeled off the Mylar and the stylus run over the Mylar again. Results showed no measurable depression.

Finally, a check was made by stacking, on a copper datum, rubber cement, 0.7-mil mica, rubber cement, and 0.25-mil Mylar. The total measured 1.15 mils, giving an average thickness of 0.1 mil for each layer of rubber cement.

(2) SHIFT MATRIX. A previous report[16] described a mode of operation for a 24 x 24 shift matrix. The disadvantage of that mode was the 1-amp d-c bias required. A new mode has been found which eliminates the need of a bias and is shown in Figure 7a. Figure 7b is the pulse sequence for this mode. H_T represents the shift allow and initially rotates the magnetization vector 90° from the "easy" axis. The digit pulse, represented by H_L, is applied during H_T and held on while H_T is removed. Readout is on the trailing edge of H_T. A "one" is transferred by applying H_T and H_L pulses as described. For a "zero," no H_L is present. Under this condition, the film should break up when H_T is removed. If no digits are to be transferred by a film, then no H_T pulse is used. Since readout is from the trailing edge of an H_T pulse, there will be no flux change at readout time.

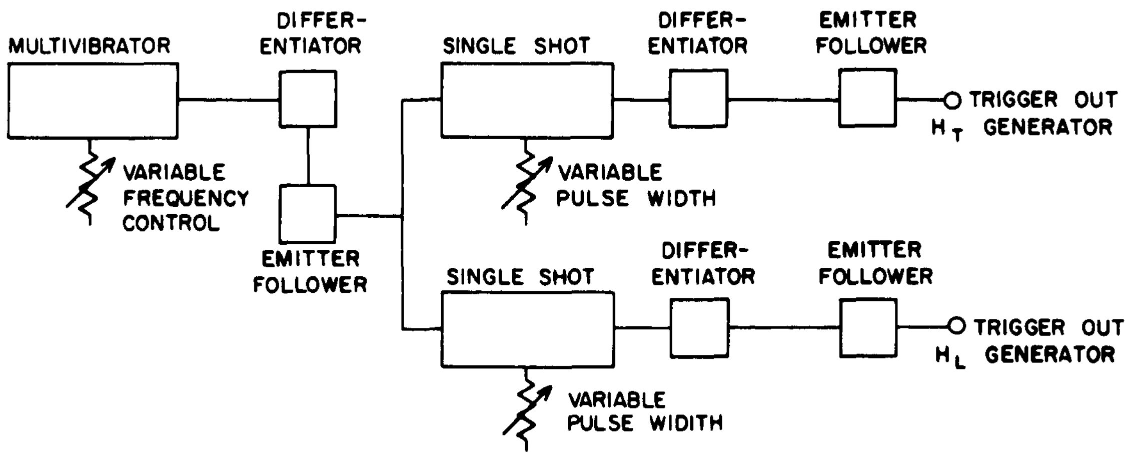
The test fixture for these tests was described in a previous report.[17] Avalanche drivers using a 2N645 are used in these tests instead of the Dumont 404 generator previously described. A trigger circuit was built to allow flexibility in the timing of the drive pulses. A block diagram of the trigger circuit is shown in Figure 8.



(a) Vector Diagram (b) Pulse Sequence

Figure 7. Operation Mode for 24 x 24 Shift Matrix

16. Second Quarterly Progress Report, Project Lightning, Phase III, Volume II.
17. Ibid.



NOTE:
Trigger out is on
trailing edge of
single-shot pulse.

Figure 8. Trigger Circuit

In testing this mode, 0.050-inch diameter films were used on the 0.030-inch wide etched circuits. An 8 x 8 array of 0.050-inch films was tested to find the variation of signals over the plate. The films were on a mica substrate. Only a single film was used, which neglects any demagnetizing effects. The pulse sequence was shown in Figure 7b. The current for H_T was 400 ma or 3.2 oe and I_T equal to 500 ma or 4 oe. Only five of the eight rows were checked. The average output signal was ≈ 3.8 mv and the average signal-to-noise ratio was ≈ 12:1.

The above experiment used only a single film. A preferred method would involve a film pair. When a film was placed on top of the circuit, a very small increase in signal resulted. A new circuit was fabricated with a total thickness of 0.0014 inch instead of the former 0.0045 inch. By using a second ground plane, the added signal from the second film was 70 percent more than that found with only a single film.

Tests were made on a 4 x 4 etched circuit array. Only a single film location was used. A great deal of difficulty arose in cancelling out the common-mode noise. The film size here was 0.030-inch diameter with a 0.068-inch center-to-center spacing. Drive fields for this circuit were somewhat high, $H_T \simeq 6.2$ oe, $H_L \simeq 2$ oe. Output voltages are $\simeq 2$ mv and signal-to-noise ratio about 10:1. This circuit is in need of redesign to reduce common mode noise. Since shift matrix studies have started in other groups of Project Lightning, the effort here has been shifted to new techniques for shift matrices.

(3) HIGH-DENSITY STORAGE. High-density bit storage has been found to be coincident with high-speed memory operation. Previous approaches to this high-speed, high-density storage have involved individual spots 0.010 inch in diameter. Later it was found necessary to increase the bit size to 0.020 inch. With the desire to increase speeds beyond that of the Lightning Test Machine memory, it was felt necessary to reduce the size of the bits again. Other investigations have shown that a bit may be defined by an area determined by the applied field. This approach allows the selection of individual bits along a strip of permalloy.

Figure 9 shows a diagram of the film used in this series of experiments. The "easy" axis is shown along the short direction of the film. The memory operation proposed is a word-organized type. A common H_L line represents the digit line, and the transverse fields are produced by each of the 20 H_T lines. These H_T lines represent word lines. Figure 10 shows the test fixture with these etched lines mounted. The single loop or top layer is the H_L line. The H_T lines fan-out at the ends for easier connecting. Three adjacent lines were used. These lines are 0.007 inch wide and 0.020 inch center-to-center, giving 50 bits to the inch.

A Kerr magneto-optic apparatus was used to study the permalloy strip. The strips were 1 mm x 1 cm. A film pair was used to reduce demagnetization fields. Thickness of the film was 1900 A. Currents used were + I_L = 250 ma, -I_L = 325 ma, and I_T = 275

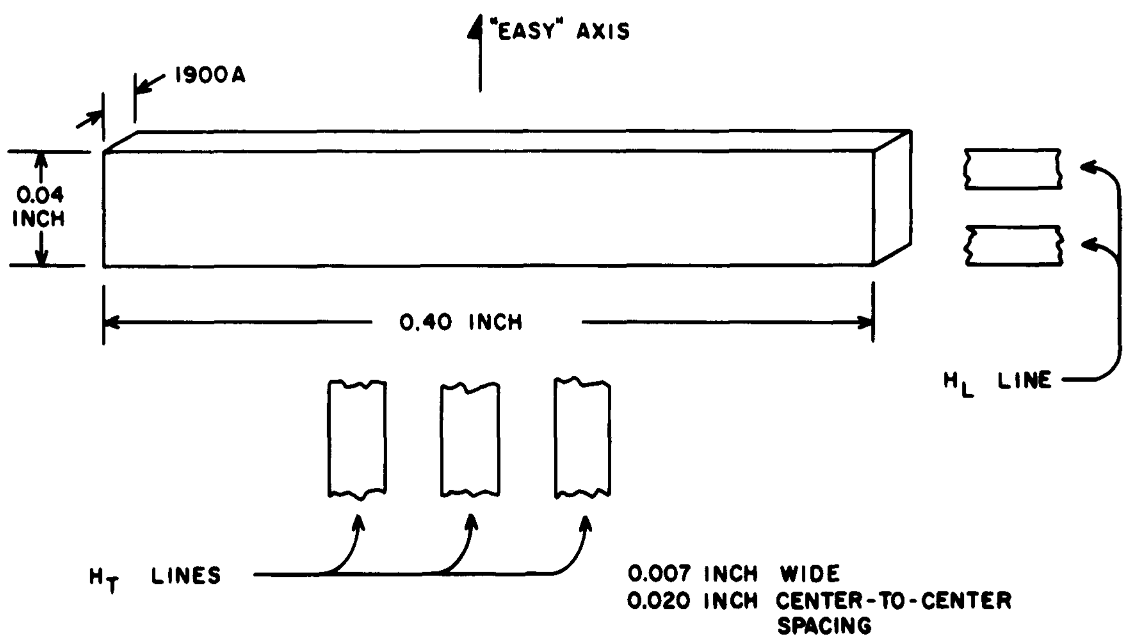


Figure 9. Permalloy Film Strip

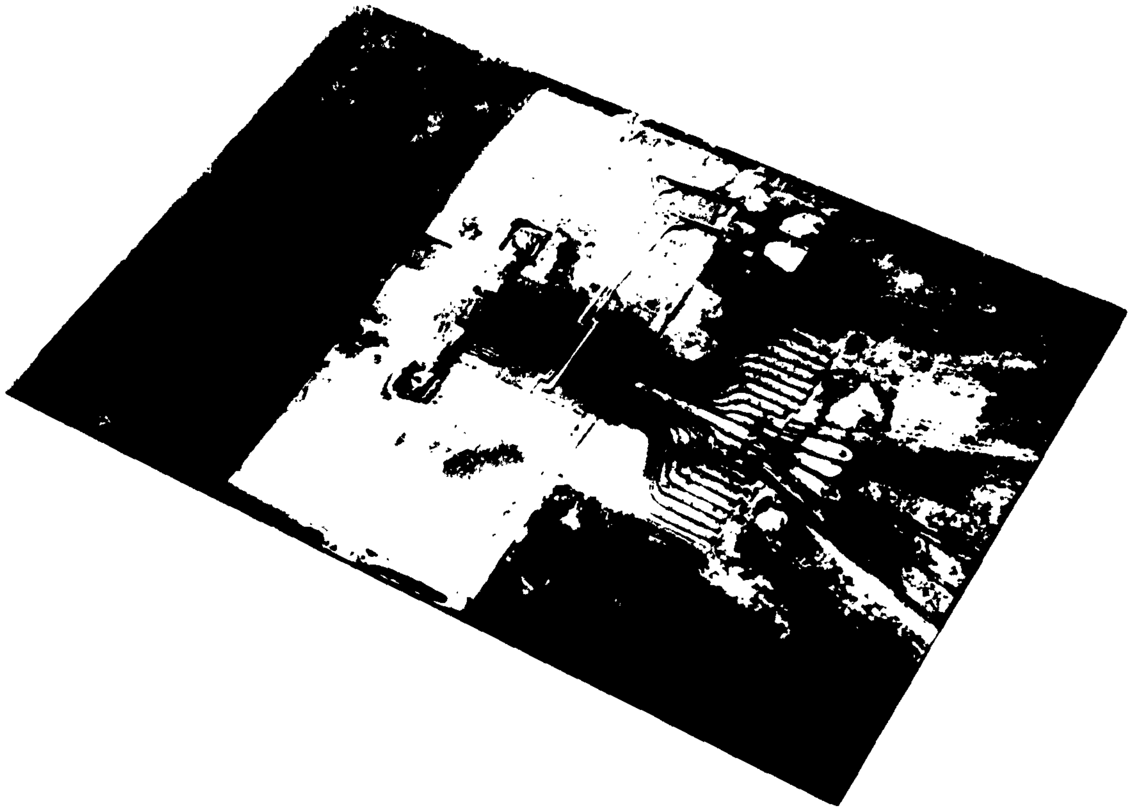


Figure 10. Test Fixture with Etched Circuits Mounted

ma. The larger value of current for $-I_L$ was necessary because of the magnetizing force of the adjacent film[18] area.

Currents were applied by actuating a pushbutton connected to a d-c regulated supply. This method produces a long pulse and allows the domains to grow by wall motion. Up to 25 transverse pulses were applied with H_L left on. The domains increased in size, but an appreciable area was still left between the switched areas. Figure 11 shows the three switched domains as dark areas. Of particular interest is the size of the light areas between the bit-domains. This light area indicates the degree of separation and independence of adjacent bits when stored at 50 per inch. A memory seems quite feasible with bits of this size.

18. Third Quarterly Progress Report, Project Lightning, Phase III, Vol. II, p. 79.

The pattern for the H_T circuits was reduced 50 percent so that a study could be made at 100 bits per inch. This gives the H_T lines a width of 0.0035 inch with a 0.0010 inch center-to-center spacing. In this test five H_T lines were used, and each had a current of 175 ma. The H_L line was kept the same as before, 0.040 inch wide. The current was 250 ma. Fields for these lines are $H_T \approx 60$ oe/amp and $H_L \approx 6$ oe/amp. Figure 12 shows the effect of pulsing the center line 50 times and the four outside lines 25 times each. Although some tendency to merge is indicated, some light area still exists between each domain. Later tests have shown that if an 80-nsec pulse is used for H_T, the size of the domains does not become nearly so great.

Further tests still need to be made to determine what causes domain growth and the control of this growth.

(4) TUNNEL DIODE PERMALLOY FILM DRIVERS. During the last quarter, work has been done on tunnel diode driven permalloy films using thin drive lines of various widths.

Drive lines are constructed from chemically deposited copper which has been subsequently electroplated. Initial chemical deposition produces a 1000 A to 5000 A layer which can be electroplated to any desired thickness. Finally, the drive lines are etched to desired width.

Experimental work has used drive strips of thicknesses from 1000 A to 3000 A. Since the minimum rise times are about 1.5 nsec, the upper limit of frequencies encountered will be about 250 Mc. At this frequency because skin depth is about 4000 A, the lines

Figure 11. Bit Domains, 0.020 Inch Center-to-Center

Figure 12. Bit Domains, 0.010 Inch Center-to-Center

should not limit field rise times or greatly hamper film switching speeds by trapping film flux.

Tunnel diodes used for drivers have 100-ma peak current in a low-inductance package. Two materials have been used, Ge and GaAs. Both have rise times of 1.5 to 2.0 nsec.

With the circuit shown in Figure 13 and Figure 14 a fast rise-current pulse of 60 to 70 ma (depending on load termination and bias) is delivered to the load. A small positive trigger-current pulse triggers the diode to its high-voltage state, and the current is switched to the strip line. To restore the diode to the low-voltage state, the input trigger is differentiated to give a negative pulse. To obtain a minimum rise time, inductance in series with the drive lines must be minimized. As termination, a carbon pillbox resistor is inserted at the far end of the transmission line. Connections are made with silver-conducting paint.

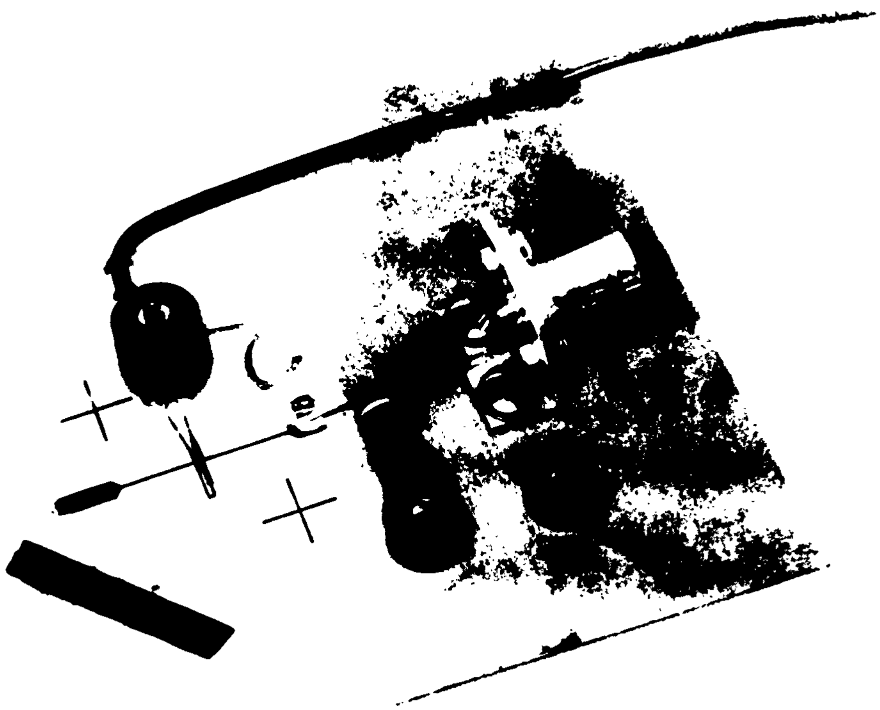
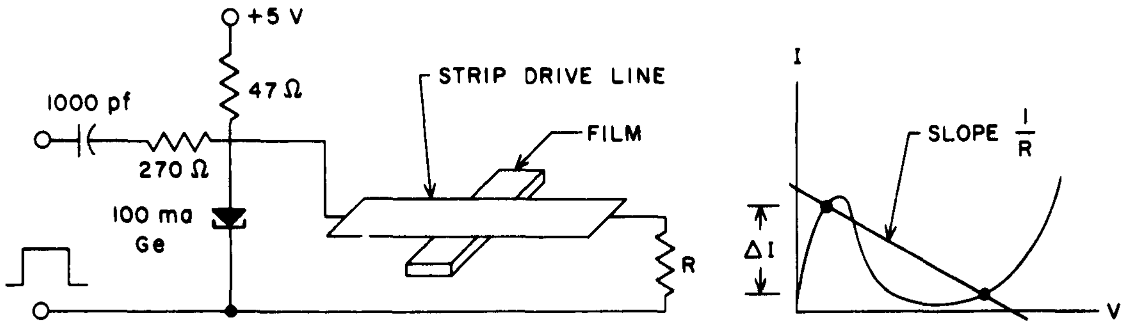


Figure 13. Tunnel Diode Film Driver



(a) Circuit Arrangement (b) I *vs* V

Figure 14. Tunnel Diode Film Driver with Load Line

Long strips of permalloy films 10 mils wide are used as shown in Figure 15. The intersection area of the two strip lines defines the memory storage area. A fast rise current pulse drives a narrow section of the film transversely, and the longitudinal flux change is sensed simultaneously.

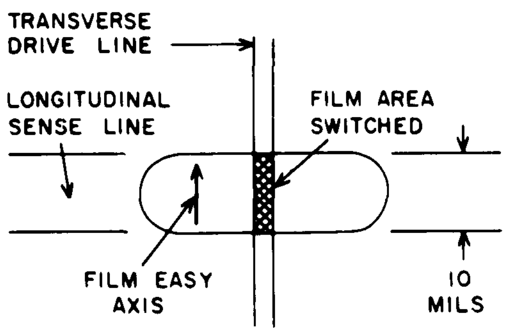
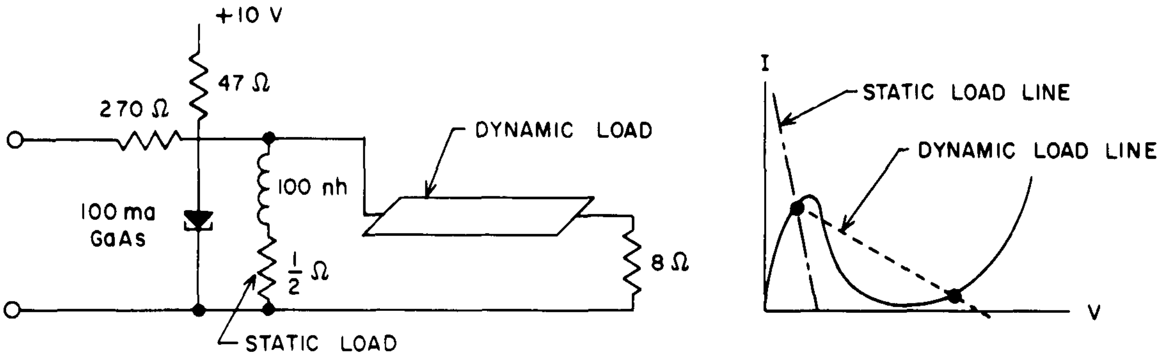


Figure 15. Film Strip Showing Small Switched Area

Film signals of 2 to 5 mv are commonly observed from these narrow sections; as much as 10 mv has been seen. Switch times are about 2 nsec long for most films. Drive line widths of from 1 mil to 10 mils with a 10-mil sense line are used. With a typical 2-mil wide line, a 60-ma current pulse produces a field pulse of $H = 40\pi\Delta I$ = 7.5 oe with a rise time of about 1.5 nsec.

Because of the non-zero voltage across the tunnel diode biased in the low-voltage state, there will be a standby current in the drive line. This will result in a transverse bias on the films, but if the bias is small compared to the anisotropy field, this bias will not be destructive. For the circuit shown in Figure 16 the bias would be about $H_b = 40\pi\frac{V_{LO}}{R_L} = 0.75$ oe for a 2-mil drive line; this about 0.1 to 0.2 H_K. If the bias does not increase the threshold field for rewrite, it might actually be desirable. If the field pulse is $H_p < H_K$, the field provided by the bias will rotate the magnetization towards the "hard" axis so that the same current pulse will provide more film output for the biased condition than for the unbiased condition provided $H_p + H_b \leq H_K$.



(a) Circuit Arrangement (b) I *vs* V

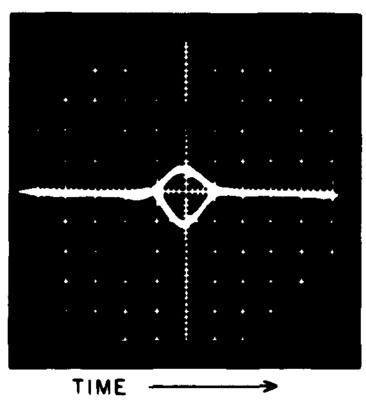
Figure 16. Start Pulse Film Driver

Figure 17 shows "one" and "zero" output of a sense line into a 50-ohm termination. The tunnel diode used is a 100-ma RCA GaAs driving a 1-mil wide line. In most cases drive line impedances have not matched load terminations, but because of the short length (~ 3 cm) of the line this apparently has not affected current rise times greatly.

A modification of the circuit shown in Figure 13 is presented in Figure 16. This driver will deliver about a 70-ma pulse a few nsec long, depending on the inductor size.

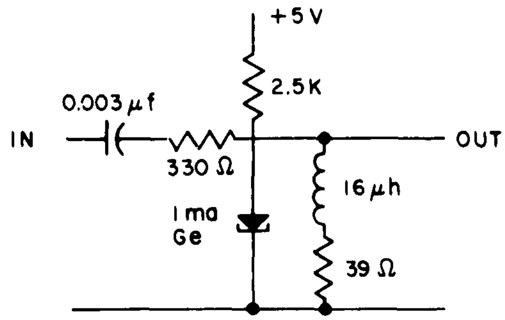
Circuits, Figure 18, have been built with the intention of using film outputs to trigger a tunnel diode detector which gives a relatively high-voltage output, which in turn may be used to trigger another high-current diode for a rewrite pulse. The detector gives an output for a positive trigger, but none for a negative trigger.

A 1-ma diode has been triggered successfully from less than 2 mv from a 50-ohm line, but because the diode was slow, T_r = 12 nsec, it could not be used with those film

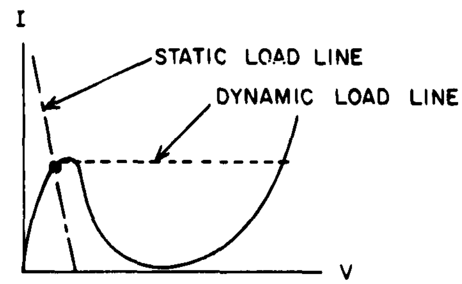


Vertical Calibration 3.3 mv/div
Horizontal Calibration 1 nsec/div

Figure 17. "One" and "Zero" Film Signal



(a) Circuit Arrangement



(b) I *vs* V

Figure 18. Film Output Detector

outputs. A 5-ma diode with a faster rise time has been used but it requires a 20-mv trigger. Output signals are 200 to 400 mv with 50 to 150 nsec width.

Circuits with two tunnel diodes are being built with the intent of using a small signal to trigger a high-current (100 ma) pulse for film writing. A completed circuit has used a triggered 1-ma diode to drive another 1-ma diode on and off with the result of a square current pulse. Tunnel diode rise times have limited the speed. Experimental work is under way to produce a short current pulse from a 50-ma diode which has been triggered by a 5-ma diode.

Plans are to design and build a 2 x 2 film memory using tunnel diode circuits. The memory would readout on request and would then rewrite the same or different information. Memory elements would be in a permalloy strip with location defined by the 2 x 10-mil intersection of the drive strip lines.

Domain patterns have been observed in 40 x 400-mil permalloy film pairs by transversely driving a 10 x 40-mil section of the large film while biasing it with a small reverse longitudinal field. Continued pulsing of the transverse drive line in the presence of the bias produces a reverse domain whose width grows with the number of pulses. Saturation width observed is about 20 mils for a 10-mil drive line after a few hundred thousand pulses for typical drive amplitudes.

Domains as narrow as 2 mils have been seen on these 40 x 400-mil films, indicating that ultimate memory sizes of at least 200 elements per inch are possible, though other considerations may limit the density.

2. MATHEMATICS AND LOGIC RESEARCH

The general-purpose logic array has been improved so that the control inputs are reduced to a four-bit word that may be used directly (without decoding). Various adaptions of the majority-logic comparator are described, and the component count and speed are given in terms of word length. A theorem that converts majority expressions to corresponding minority expressions is given and applied to the 24-bit comparator.

a. IMPROVED GENERAL-PURPOSE LOGIC ARRAY. A previous report[19] gives a general-purpose logic array that accepts two binary literals A and B and a seven-bit control word as inputs and produces a Boolean function of A and B as the output. The control word selects the function, which may be any of the 16 possible Boolean functions of 2 literals.

The array is described by the following equation:

$$f(A,B) = \left[(A\#X_0\#B)\#X_1\#(\bar{A}\#X_2\#B)\right]\#X_3\#\left[(A\#X_4\#\bar{B})\#X_5\#(\bar{A}\#X_6\#\bar{B})\right] \qquad (1)$$

Values of the control bits X_0 - X_6 required to produce each of the functions are tabulated below:

f	X_0	X_1	X_2	X_3	X_4	X_5	X_6	K_0	K_1	K_2	K_3
$A\cdot\bar{B}$	0	0	0	1	0	0	1	0	0	0	1
$\bar{A}\cdot\bar{B}$	0	0	0	1	1	0	0	0	0	1	0
$\bar{B}$	0	0	0	1	1	0	1	0	0	1	1
$A\cdot B$	0	0	1	1	0	0	0	0	1	0	0
A	0	0	1	1	0	0	1	0	1	0	1
$A\cdot B+\bar{A}\cdot\bar{B}$	0	0	1	1	1	0	0	0	1	1	0
$A+\bar{B}$	0	0	1	1	1	0	1	0	1	1	1
$\bar{A}\cdot B$	1	0	0	1	0	0	0	1	0	0	0
$\bar{A}\cdot B+A\cdot\bar{B}$	1	0	0	1	0	0	1	1	0	0	1
$\bar{A}$	1	0	0	1	1	0	0	1	0	1	0
$\bar{A}+\bar{B}$	1	0	0	1	1	0	1	1	0	1	1
B	1	0	1	1	0	0	0	1	1	0	0
$A+B$	1	0	1	1	0	0	1	1	1	0	1
$\bar{A}+B$	1	0	1	1	1	0	0	1	1	1	0
1	1	0	1	1	1	0	1	1	1	1	1
0	0	0	0	1	0	0	0	0	0	0	0

19. Third Quarterly Progress Report, Project Lightning, Phase III, Vol. II, p. 110.

Inspection of this tabulation reveals the X_1 and X_5 are unconditionally '0', while X_3 is unconditionally '1'. These unconditional bits may be entered into the equation and removed from the control word. The remaining bits of the control word X_0, X_2, X_4, and X_6 are denoted by K_0, K_1, K_2, and K_3, respectively and included in the above tabulation. With these substitutions, (1) becomes

$$f(A,B) = \left[(A\#K_0\#B)\#0\#(\bar{A}\#K_1\#B) \right] \#1\# \left[(A\#K_2\#\bar{B})\#0\#(\bar{A}\#K_3\#\bar{B}) \right]$$

Since four bits are required to select one of 16, the K codes tabulated above are minimum. Indeed, the K code is used directly without decoding; K could, for example, be a designator in an instruction word.

The improved array is shown in Figure 19.

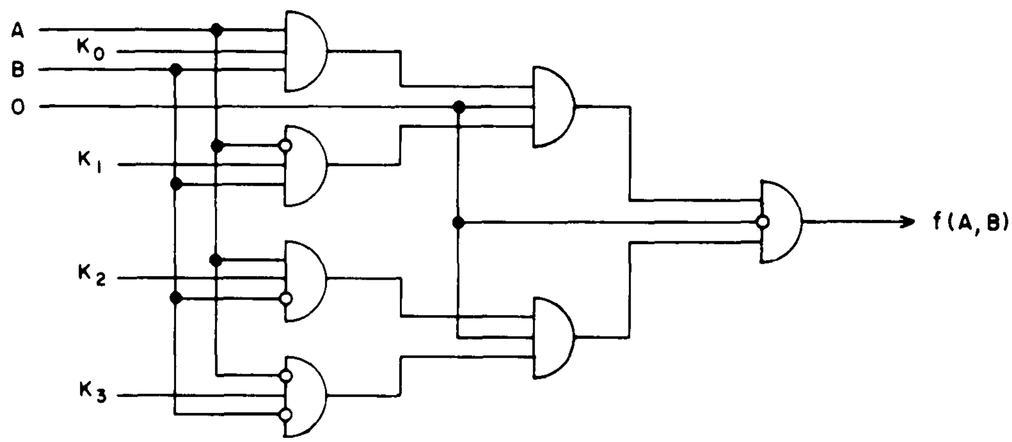


Figure 19. Improved General-Purpose Logic Array

b. MAJORITY-LOGIC COMPARATOR. A previous report[20] gives a network of 43 triadic binary majority-decision elements that compares two 24-bit words and requires only five levels of logic (delay times). It is of interest to determine, more generally, how many logic levels and decision elements are required to compare two k-bit words in the same manner. The expression

$$2^{n-1} \leq k < 2^n$$

uniquely defines an integer n. It appears that the number of logic levels is given by n and the number of decision elements by $2k - n$.

20. Fourth Quarterly Progress Report, Project Lightning, Phase III, Vol. II, p. 49.

Neither the number of components nor the number of logic levels rises exponentially with k; the former rises linearly with k while the latter rises stepwise with the logarithm of k. In comparison with the corresponding low-speed comparator, the high-speed comparator uses less than twice as many components and is many times faster, the advantage increasing exponentially with k.

A comparator of this type can easily be adapted to various kinds of arithmetic. For example, it can be adapted to ones- or twos-complement arithmetic merely by reversing the negations of the highest-order data bits (for example, A_{23} and B_{23}). Data words A and B are then compared as signed algebraic numbers.

An interesting effect is produced by using $\overline{C}$, the negated output, as the X input. If inputs A and B are continuously applied, the output becomes an alternating series 0101... for $A = B$. This arrangement does not affect the operation for $A \neq B$. The result is that all three conditions ($A > B$, $A < B$, $A = B$) can be distinguished in two periods of operation.

It is shown below that the structure of the comparator is essentially unchanged by the substitution of minority elements for majority elements. The above remarks therefore apply *mutatis mutandis* to the minority-logic comparator as well.

c. MAJORITY-MINORITY CONVERSION THEOREM. Recent developments in semiconductor circuit technology make it appear probable that networks of minority-decision elements may have to be designed. One approach to this problem depends on a theorem that converts majority-logic networks to the corresponding minority-logic networks. The theorem is stated as follows:

$$f(X, Y, \ldots Z, \#) \equiv f(X^x, Y^y, \ldots Z^z, *) \qquad (2)$$

The left-hand member represents any majority function f of binary literals X, Y, etc. The right-hand member represents the same functional form with X^x, Y^y, etc., substituted for X, Y, etc., respectively, and '*' substituted for '#'. The theorem states that the functions are identical. The special notation in the right-hand member is defined below:

> x means the number of pairs in parentheses that enclose X; y, etc., are defined similarly.
>
> X^x means X if x is odd, or $\overline{X}$ if x is even; x is hereafter referred to as the *level* of X.
>
> * means the minority-decision operator defined by $X*Y*Z \equiv \overline{X\#Y\#Z}$.

Because of the way that exponents are defined, the original function f must be free of superfluous parentheses; that is, it must include one pair of '#'s that are not enclosed in parentheses.

The application of (2) is illustrated below by the conversion of the 24-bit majority-logic comparator[21] to a corresponding minority-logic network. The 24-bit majority-logic comparator is represented by the following equations:

$$C_2 = (X\#A_0\#\bar{B}_0)\#(A_1\#A_2\#\bar{B}_2)\#(A_2\#\bar{B}_1\#\bar{B}_2) \tag{3}$$

$$\begin{aligned} C_6 = C_2\# &\left[(A_3\#A_4\#\bar{B}_4)\#(A_5\#A_6\#\bar{B}_6)\#(A_6\#\bar{B}_5\#\bar{B}_6)\right] \\ \# &\left[(A_4\#\bar{B}_3\#\bar{B}_4)\#(A_5\#A_6\#\bar{B}_6)\#(A_6\#\bar{B}_5\#\bar{B}_6)\right] \end{aligned} \tag{4}$$

$$\begin{aligned} C_{14} = C_6\# &\Big\{\left[(A_7\#A_8\#\bar{B}_8)\#(A_9\#A_{10}\#\bar{B}_{10})\#(A_{10}\#\bar{B}_9\#\bar{B}_{10})\right] \\ \# &\left[(A_{11}\#A_{12}\#\bar{B}_{12})\#(A_{13}\#A_{14}\#\bar{B}_{14})\#(A_{14}\#\bar{B}_{13}\#\bar{B}_{14})\right] \\ \# &\left[(A_{12}\#\bar{B}_{11}\#\bar{B}_{12})\#(A_{13}\#A_{14}\#\bar{B}_{14})\#(A_{14}\#\bar{B}_{13}\#\bar{B}_{14})\right]\Big\} \\ \# &\Big\{\left[(A_8\#\bar{B}_7\#\bar{B}_8)\#(A_9\#A_{10}\#\bar{B}_{10})\#(A_{10}\#\bar{B}_9\#\bar{B}_{10})\right] \\ \# &\left[(A_{11}\#A_{12}\#\bar{B}_{12})\#(A_{13}\#A_{14}\#\bar{B}_{14})\#(A_{14}\#\bar{B}_{13}\#\bar{B}_{14})\right] \\ \# &\left[(A_{12}\#\bar{B}_{11}\#\bar{B}_{12})\#(A_{13}\#A_{14}\#\bar{B}_{14})\#(A_{14}\#\bar{B}_{13}\#\bar{B}_{14})\right]\Big\} \end{aligned} \tag{5}$$

$$\begin{aligned} C_{23} = C_{14}\# &\Bigg[\Big\{(A_{19}\#A_{20}\#\bar{B}_{20})\#(A_{20}\#\bar{B}_{19}\#\bar{B}_{20})\#\big[(A_{15}\#A_{16}\#\bar{B}_{16})\#(A_{17}\#A_{18}\#\bar{B}_{18}) \\ &\#(A_{18}\#\bar{B}_{17}\#\bar{B}_{18})\big]\Big\}\#\left[A_{23}\#\bar{B}_{23}\#(A_{21}\#A_{22}\#\bar{B}_{22})\right] \\ &\#\left[A_{23}\#\bar{B}_{23}\#(A_{21}\#\bar{B}_{21}\#\bar{B}_{22})\right]\Bigg]\#\Bigg[\Big\{(A_{19}\#A_{20}\#\bar{B}_{20}) \\ &\#(A_{20}\#\bar{B}_{19}\#\bar{B}_{20})\#\big[(A_{16}\#\bar{B}_{15}\#\bar{B}_{16})\#(A_{17}\#A_{18}\#\bar{B}_{18})\#(A_{18}\#\bar{B}_{17}\#\bar{B}_{18})\big]\Big\} \\ &\#\left[A_{23}\#\bar{B}_{23}\#(A_{21}\#A_{22}\#\bar{B}_{22})\right]\#\left[A_{23}\#\bar{B}_{23}\#(A_{22}\#\bar{B}_{21}\#\bar{B}_{22})\right]\Bigg] \end{aligned} \tag{6}$$

21. Fourth Quarterly Progress Report, Project Lightning, Phase III, Vol. II, p. 49.

Conversion of (6) by theorem (2) to minority form begins with C_{14}, which is enclosed in no parentheses. Zero is construed as an even number, so C_{14} is negated in the converted expression. The next literal, A_{19} is enclosed by three parentheses, so it is not negated in the conversion. With a few exceptions, the remaining literals are also third level and therefore unnegated in conversion. The exceptions are as follows:

A_{23} and $\bar{B}_{23}$ (second level); A_{15} - A_{18} and B_{15} - B_{18} (fourth level).

Inspection of (5) shows that C_6 is zero level and that all other literals are third level. It follows that conversion of C_{14} to minority form negates C_6 and leaves the other literals unchanged. But the minority-logic form of (6) requires $\bar{C}_{14}$, so the final converted form of (5) has C_6 unchanged, but all other literals negated. This follows readily from the minority form of De Morgan's law:

$$\overline{X*Y*Z} \equiv \bar{X}*\bar{Y}*\bar{Z} .$$

Inspection of (4) shows that all literals are on even levels (0 and 2) and therefore are negated by conversion to minority form.

Inspection of (3) shows that all literals are first level and therefore not negated by conversion to minority form. But the majority-logic form of (4) requires $\bar{C}_2$, so the final converted form of (3) has all literals negated.

The above discussion is summarized as follows: the minority-logic 24-bit comparator is given by (3)-(6) with '*'s replacing '#'s throughout and negation bars appearing only on X, A_0 - A_{18}, A_{23} and B_{19} -B_{22}. It follows that the comparator design given in the previous report may be adapted to minority elements merely by negating a different set of inputs.

3. LIGHTNING TEST MACHINE

a. HIGH-SPEED MEMORY STACK DESIGN

(1) MECHANICAL

(a) FILM CORE DEPOSITION AND EVALUATION. A number of strip film core arrays (22 mils wide by 16 film elements long) were made during this period, both by evaporation through mask and by etching from sheet films (mirrors). Evaluation results are discussed in part 2 of this section.

Masks for the following film core array configurations have been received during this period:

1) 22 x 30-mil rectangular film elements on the June Demonstration Unit (JDU) size glass substrate (1.160 x 1.500 inches x 0.006 inch). This array is similar to the strip array except that there is a 10-mil gap in the permalloy film between film elements. The major axis of the permalloy elements lies on the center of the digit lines.

2) 22 x 30-mil rectangular film elements as above on the Lightning Test Machine (LTM) size substrate (1.500 x 2.080 inches x 0.006 inch).

3) 20 x 50-mil film elements on the LTM size substrate.

4) 10 x 50-mil film elements on the LTM size substrate.

All film core arrays on the LTM size substrate have film elements spaced on 40-mil centers in the word line direction and on 100-mil centers in the digit line directions.

Approximately one dozen of each of the above film core arrays have been produced for the project.

Six sheet film core arrays were furnished to the circuit laboratory with a mask as in 1) above, and etched film core arrays were made. This is an experiment to eliminate "easy" axis wander which is sometimes troublesome in vacuum-deposited arrays having small individual film elements.

(b) LIGHTNING CIRCUIT OVERLAY PROGRESS

1 DRO. Approximately 20 etched copper circuit overlays in the JDU configuration were delivered to the project during this period. They varied as follows:

1) 6 assemblies, multi-split in word and digit lines, sense lines unbalanced.

2) 6 assemblies, multi-split in word and digit lines, sense lines balanced.

3) 8 assemblies, single-split in word and digit lines, sense lines unbalanced.

Two each of 4 x 4 film element test overlays Nos. 8, 9, 10, and 10A were delivered during this period. Test arrays Nos. 8 and 9 have straight sense lines; test arrays Nos. 10 and 10A have no sense lines; No. 10 has a 10-mil word line; and No. 10A a 20-mil word line. The digit and word lines vary in width and multi-split configuration. Digit line spacing is 100 mils, and word line spacing is 40 mils.

Design work on the LTM memory plane is proceeding. In an attempt to minimize or eliminate the word and digit noise problem in the JDU design, four different circuit overlay designs having various arrangements of sense and drive lines have been produced. The circuitry configuration of the digit, sense, and word lines of the LTM overlay will be finalized after these four test planes have been evaluated.

A JDU circuit overlay was constructed with a 1.0-mil copper shield plane laminated to the epoxy glass baseboard. This results in shield planes equi-distant from both the top and bottom layers of the circuit array.

2 SHIFT MATRIX. Ten 4 x 4 film element test overlays were delivered to the project during this period.

3 SEARCH MEMORY. The second 24-bit by 64-word test plane was delivered during this period. Packaging of the third search memory plane is partially complete. This overlay has three layers of circuits: a word line, a digit line, and a bias line layer.

4 NEW DEVELOPMENT WORK. Rolled copper foil, 1/8 and 1/4 mil, pin-hole free, will be used to make thinner circuit overlays. Overlays that are about 1 mil thick should be possible by using the 1/8 mil for circuitry.

A Laboratory Services Report, PX 800-984, has been prepared on electroless copper-deposited circuits using the Shipley Company Cudeposit processes. As of this date, no usable Project Lightning circuit overlays have been produced by this process because of the following weaknesses:

1) The circuitry produced by this method has an excessive number of pin holes.

2) Fine hair-line cracks appear in the circuitry after a day or two. This is probably caused by the expansion differential between the copper and the insulating film. The electroless copper is lower in tensile strength.

Fine copper wire has been successfully welded to the terminal bits of a JDU circuit overlay. A series-type, capacitor-discharge resistance welder was used. The welded joint array was encapsulated with a thin layer of epoxy, thus eliminating the low peel strength problem on resistance-welded thin metal joints.

A photomicrograph study has been started on cross sections of circuit overlays of various types of construction. This study was started because a number of overlays of the "semi-Mylarless" type using electrodeposited copper had shorts between circuitry layers. The photomicrographs (195 magnification) show that shorting occurs when high spots on relatively rough surfaces of two electrodeposited copper circuits directly oppose each other on opposite sides of a polyester insulating film. See Figure 20. The thickness of the polyester adhesive insulating film varies with the surface finish of the adjacent copper layers.

It is felt that this shorting problem can be eliminated by using rolled copper (smooth surface finish) for circuitry. See Figure 21.

Figure 22, a cross section of a thin gold circuit, shows that uniformity of plating of the lines is a problem, particularly for the word lines, and explains the high word line d-c resistance observed with the same overlays.

Figure 20. Cross Section of JDU Array Made with 1/2-Mil Electrodeposited Copper

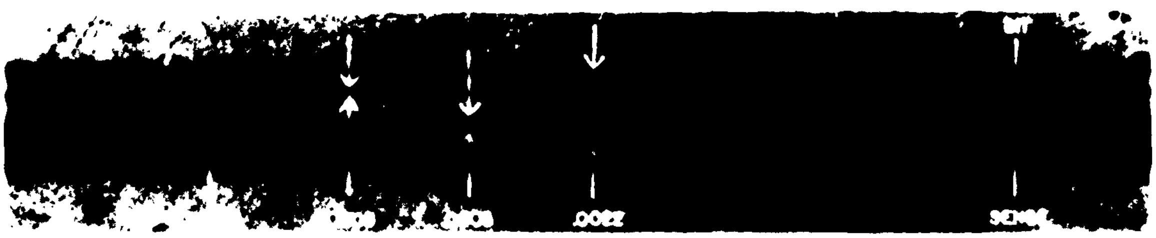


Figure 21. Cross Section of JDU Multi-Split Array Made with 1/2-Mil Rolled Copper

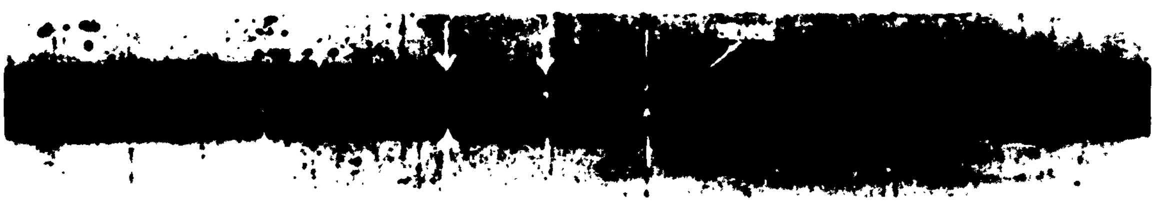


Figure 22. Cross Section of JDU Array Made with 1/20-Mil Gold

(2) ELECTRICAL TESTS

(a) DRO. Up to now all films used were 20-mil diameter round spots. Substrates with 20-mil wide strips running in the "hard" direction of magnetization were investigated during this period. The strips provided a distinct advantage over the round spots in that a relatively large sense signal was obtained with a moderate value of word current. Coupled 20-mil strips typically produced 2-mv peak sense signals (approximately twice that of round spots) using 0.4- to 0.5-amp word currents, rising in 15 to 20 nsec. Switching speeds of the strips were at least as good as those obtained from the round spots. Strip cores etched from continuous sheets appear to perform equally well.

Efforts to produce an overlay which will reduce digit noise pickup are continuing. The overlay with equally shaded sense lines mentioned in the Fourth Quarterly Progress Report, Phase III, was not successful because the sense lines were not far enough apart to pick up all the film flux. An overlay with a copper ground plane laminated to the back-up board under the circuit tabs was evaluated. This overlay reduced noise pickup somewhat, and particularly seemed to decrease the duration of the noise pulses and subsequent ringing.

Overlays now being built have a dummy digit line for each row of film spots. The dummy line shades the outer sense line in the same way the regular digit line shades the sense line which runs under the film element positions. Equal currents are sent down the digit line and the adjacent dummy line. The digit current pickup in the two sense lines theoretically cancels. Also, this type of overlay is adaptable to directional coupling, a noise cancellation scheme which will be discussed in detail in the next report. It has been found experimentally that the sense lines must be at least 40 mils apart at their centers to pick up most of the film flux. Therefore, digit density in the direction of the word drive line is reduced to half its former value by the overlay described above. The length of the word line is essentially doubled. This, however, constitutes a minor sacrifice if digit noise pickup can be controlled.

(b) SEARCH MEMORY. Work has progressed on a 128-word, 24-bit word search memory using 35-mil BICORE film elements[22]. Plans are to operate this memory in the same mode as the search memory described in the Fourth Quarterly Progress Report, Phase III. A test fixture has been built to drive 12 digit lines simultaneously. The ratio of a single "1" and eleven "0's" to twelve "0's" was four to one.

22. The BICORE film element is an NDRO memory cell which has a film of permalloy overlaying a film of a highly coercive material such as 90-10 cobalt-iron alloy.

A "1" signal has an amplitude of 1.0 mv and a duration of 40 to 50 nsec. This signal is obtained with a 200-ma drive current which rises in 20 nsec.

Tests were also performed to determine the minimum current required to write information in the 35-mil BICORE film elements. It was found that a write-in could be performed with coincident currents as low as 1.5 amp and 1.0 amp lasting for 0.15 μsec. The time duratio:. mentioned is the time the write-in pulse was at full amplitude. Rise and fall times were on the order of 0.1 to 0.15 μsec.

Readout tests have been made with a cube coil providing transverse bias. It will be necessary to obtain this bias from a more compact source in the LTM; i.e., a third layer of circuitry in the overlay. The additional layer of circuitry greatly increases the density of connectors thus resulting in a rather serious packaging problem. A three-layer overlay is now being constructed.

(c) SHIFT MATRIX. The proposed Project Lightning shift matrix will shift a 24-digit word up to 23 places in a cycle time of 100 nsec. The matrix elements are thin films which will be driven by a combination of transverse and longitudinal fields. The most promising drive scheme seems to be to have the input information determine the longitudinal field and the selected shift line provide the transverse drive. With this scheme only the selected cores are subjected to a transverse drive. If opposite polarities of longitudinal drives correspond to one-zero inputs, bipolar outputs will be available and the films will return to one of their remanent states at the end of the cycle. The output is read at the end of the transverse (shift) pulse and is dependent only on the polarity of the longitudinal field and not on the initial state of the film.

The development of a shift matrix has consisted of designing and testing three 4 x 4 test arrays. With these three arrays, it was possible to investigate several array configurations as well as several types of film elements. Circular, oblong, and line cores were all used in one or more of the test arrays.

<u>1</u> TEST ARRAY NO. 1. This first test array was designed for 30-mil circular film elements. The drive lines are multi-split and are returned through the array between the rows of film spots. The sense lines are solid, 6 mils wide and all run completely through the array. The most successful sensing arrangement was as follows (Figure 23).

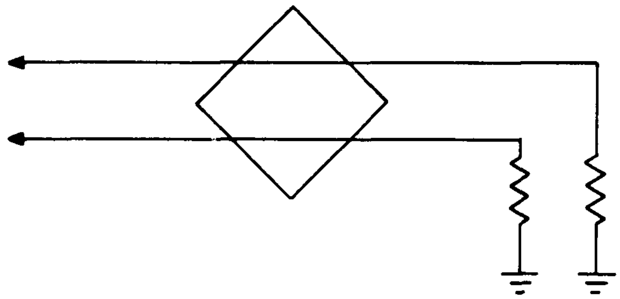


Figure 23. Sensing Arrangement for Test Array No. 1

Since noise will be induced on both sense lines and the signal only on one or the other, any noise pickup on the sense lines is eliminated by the common-mode rejection of the amplifier while the signal appears as a difference signal and will be amplified. The test results were:

1) Signal: 1 to 2 mv, 20 nsec duration.
2) Signal-to-noise ratio: 8 to 10:1 .

2 TEST ARRAY NO. 2. Array No. 2 was built using the drive line artwork from a previous 4 x 4 array built for testing of the DRO. Sense lines at 45° angles were made and added to the drive lines. Twenty-mil circular spots, strip line cores, and 22 x 30-mil oblong cores were tested on this array using the same sensing arrangement as described previously. With a transverse current of 500 ma, the longitudinal current was varied and the signal measured. The peak signal was about equal in each case, 2 mv, but with the oblong cores the peak was sharper and occurred at a lower current level.

3 TEST ARRAY NO. 3. This array has the same drive lines as No. 2 with different sense lines. Here the sense lines are parallel to the longitudinal drive line in the region of the film core, but each sense line still links the same cores as with No. 2. With this scheme a symmetrical, bipolar output is available. With 45° sense lines the flux linkage change for a "1" switch is different than that for a "0" switch, hence the unsymmetrical output.

The output from oblong cores in test array No. 3 was about 1.0 mv in either direction, using 500-ma transverse current and 125-ma longitudinal current.

4 SENSE LOOP. All the tests done with the three test arrays are essentially single-bit tests. Although the tests show good results, the sensing scheme is unsuitable for a full-size array. The reason is that a plus ("1") signal on one sense line of a pair and a minus ("0") signal on the other line will produce the same output from a differential sense amplifier. This problem is complicated because each sense loop links a different combination of drive lines and cores. Therefore, to use logic to distinguish "1" signals from "0" signals is impractical.

A series sense loop is needed so that a signal on either line will produce the same output. To connect the pairs of sense lines, a return path must be provided for each sense line through the array. The following sense loops were tried (Figure 24).

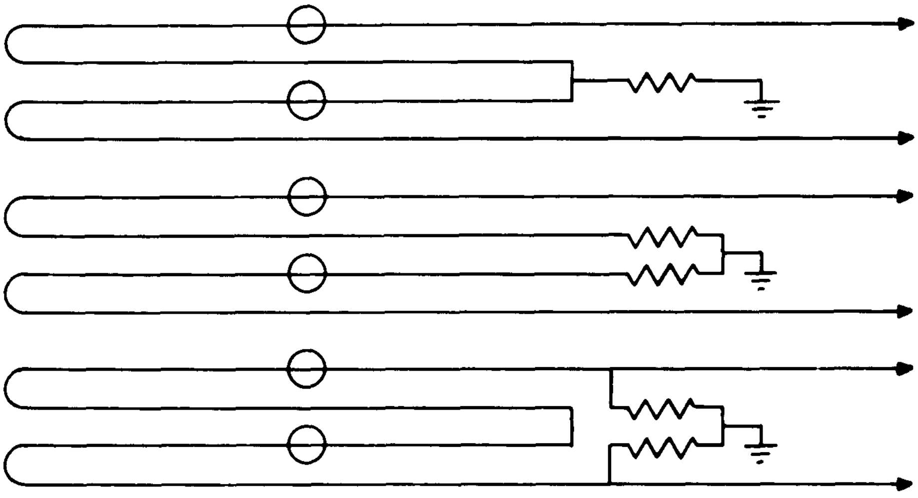


Figure 24. Sense Loops Used in Test Arrays 1, 2, and 3

In each case, overshoot and ringing were present in the output. The best results were obtained using the third scheme with 10-ohm resistors, although some amplitude was sacrificed to eliminate the ringing.

A 24 x 24 array is being designed which will utilize 22 x 30-mil oblong cores with the sense line parallel to the longitudinal line as in test array No. 3.

(d) LTM STACK ARRAY TESTER. An array tester for LTM planes and film core arrays is in the design stage, and construction of a 4 x 4 prototype has begun. The tester will check for uniformity of output, stack noise or cross talk, and alignment

of substrate with respect to wiring. How each film spot of the array performs under varied drive conditions can also be observed.

To accomplish the above functions, the tester requires a control section, a two-phase clock, and memory circuits. The control output will cycle the four words through a translation counter in the run, advance, and repeat modes. A manual write mode will be provided to write in the information.

The obsolete Lightning OR-inverter emitter-follower cards are being used for the tester logic. For a circuit diagram see Second Quarterly Progress Report, Vol. I, Third Phase, p. 23. These cards have been tested and seem satisfactory at this time.

The two-phase clock has been built and operated at frequencies from 2 to 10 Mc (corresponding to cycle times of 250 to 50 nsec). The clock was tested by driving successfully five of the above logic cards from each phase in the full range of frequencies.

At this time it is planned to use the JDU memory circuits in the array tester.

b. SENSE AMPLIFIERS

(1) INTRODUCTION. It has been decided to use low-level gating techniques to secure a satisfactory memory signal for the LTM. In the previous progress report four ways of building a sense amplifier to meet the requirements of the high-speed film memory were discussed. Low-level gating with tunnel diodes was discussed, and it was then thought that a satisfactory noise-to-signal ratio could not be achieved by this method. It is now possible to back-bias the tunnel diode so that a noise-to-signal ratio of about 20:1 can be tolerated. This type of gating will also permit logical selection of the outputs, a function that would otherwise be performed by logic circuits following the sense amplifier. Low-level gating should also reduce total loop delay by at least one logic level.

(2) AMPLIFIER DESIGN. A block diagram of the amplifier to be used is shown in Figure 25.

Primarily the amplifiers will provide:

1) Difference signal detection and amplification;
2) Class A, wide-band amplification of both channels;
3) Tunnel diode low-level gating, with a current-steering strobe control;
4) Output amplifiers for both channels that provide a signal compatible with the logic circuits.

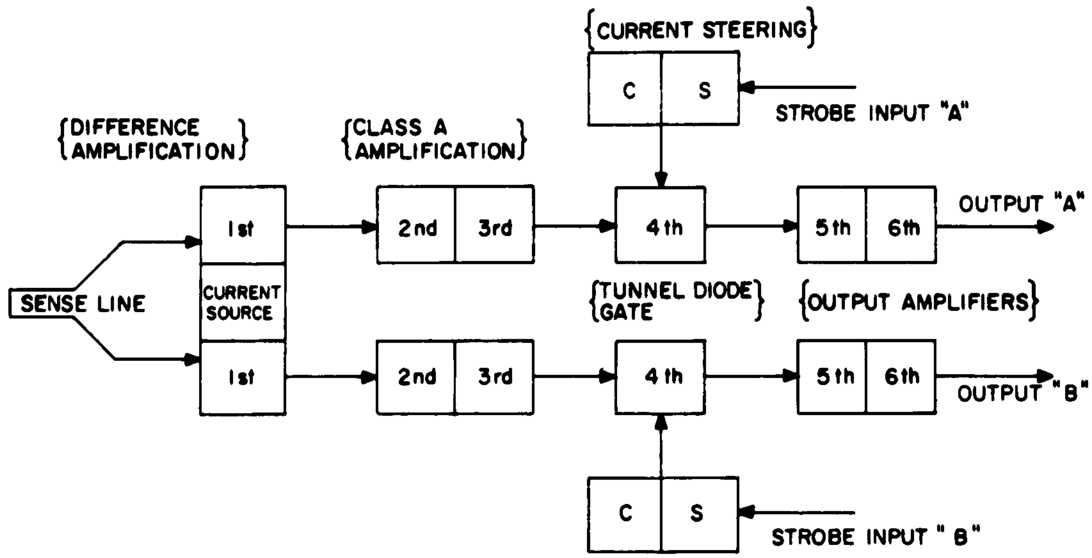


Figure 25. Sense Amplifier Functions

The complete circuit diagram is shown in Figure 26.

A good difference amplifier is necessary in the first stage because most of the "word" noise and "digit" noise is common mode. With a transistor current source a common-mode rejection ratio of 1000 for all frequencies below 200 Mc has been obtained.

Both the difference amplifier and the Class A sections have single-stage feedback to give a rise time of 4 nsec and a voltage gain equivalent of 20db for the first three stages with a 50-ohm load. (Gain is defined as the output from one side of the amplifier divided by the total difference input signal.) Since there is about 5 mv of signal from the film, the output signal current from the Class A section is about 1 ma.

The tunnel diode, acting as a low-level gate, can be triggered by the 1-ma signal from the Class A section. Figure 27 illustrates the characteristics of a typical 5-ma tunnel diode. Normally, the tunnel diode is back-biased by about 15 ma (I_R); when the strobe pulse is on, the device is forward biased to a point about 0.5 ma below the peak (I_S). When the signal is present ($I_S + \Delta i_S$) the tunnel diode switches to the 500-mv point. The current-steering strobe control is arranged so that normally the reverse bias current is supplied from the steering package. The strobe pulse turns off the transistor connected to the tunnel diode so that the bias point (I_S) is controlled by the +24-volt

NOTE:
1) Resistances in ohms and capacitances in μf unless otherwise indicated.
2) Resistors 1/4 watt ±5% unless otherwise indicated.

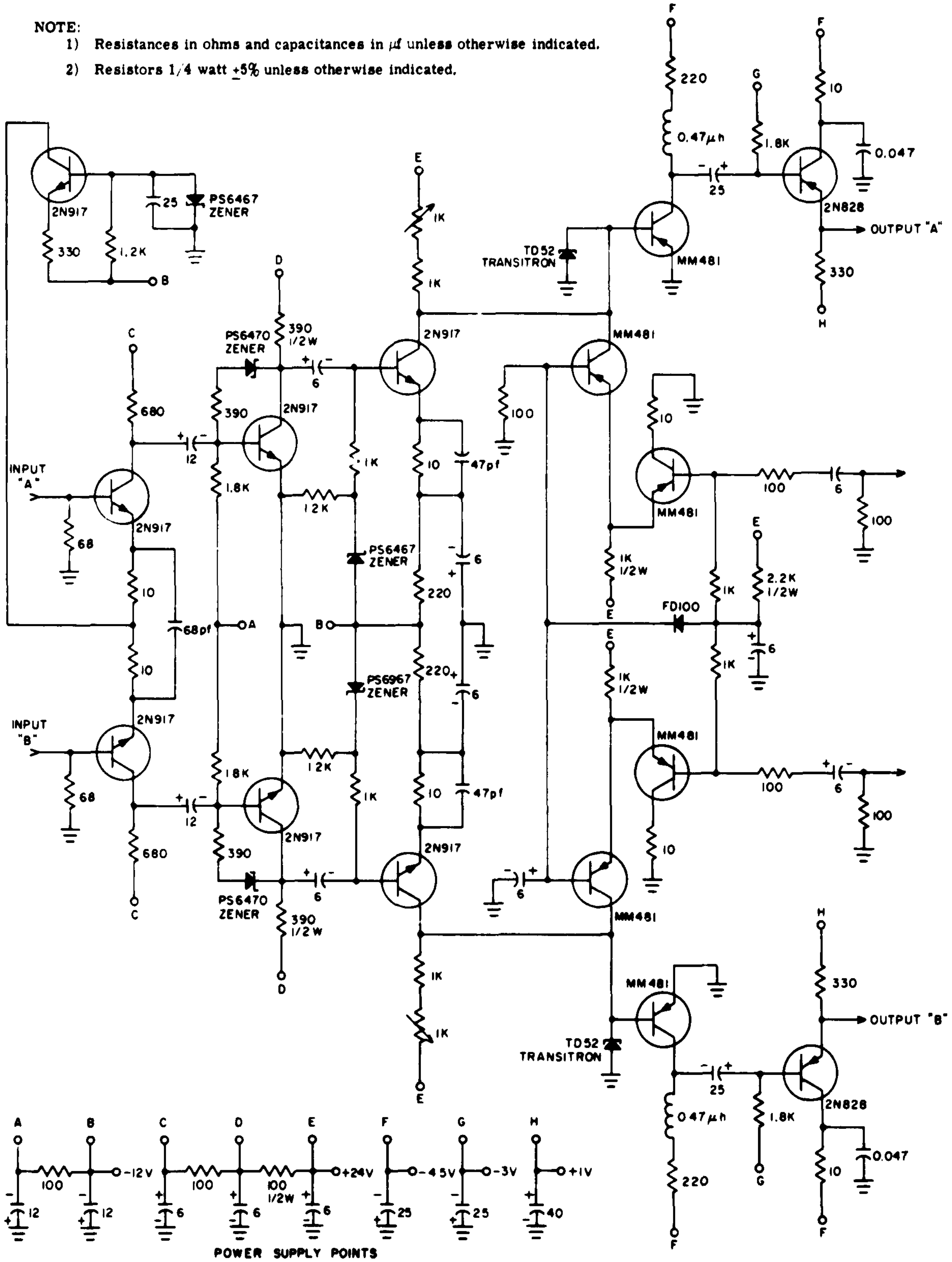


Figure 26. Sense Amplifier

supply and can be adjusted by potentiometers on each side of the amplifier. Since 20 ma of noise are required to trigger the tunnel diode when the strobe is not on, a 20:1 noise-to-signal ratio can be allowed.

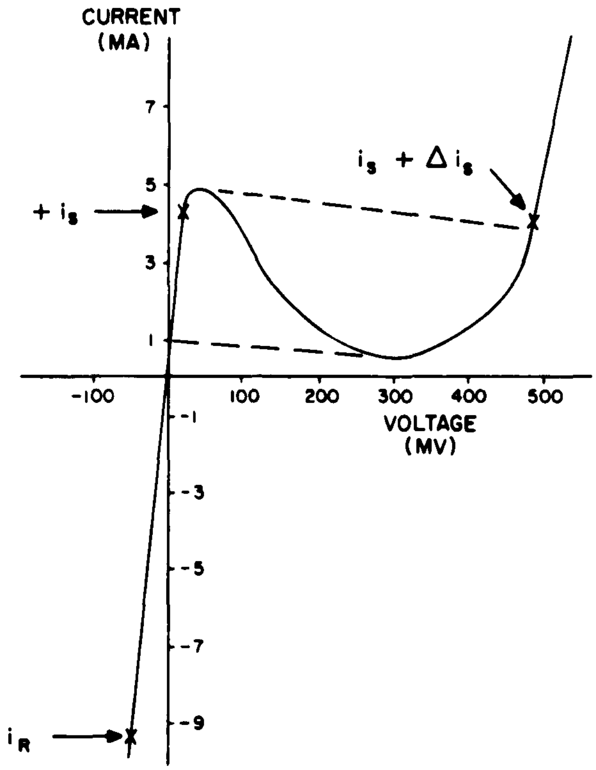
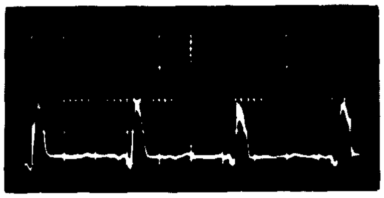


Figure 27. Characteristics of Typical 5-Ma Germanium Tunnel Diode

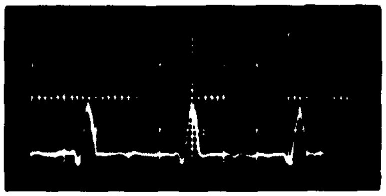
The output circuit consists of a direct coupled amplifier that is normally held off by the reverse bias of the tunnel diode; when the diode switches, the amplifier is turned on and the output is about 2.5 volts. The last stage is an emitter-follower biased to produce a 2-volt pulse compatible with the logic circuits.

(3) RESULTS. Output waveforms are shown in Figure 28. With an 80-nsec memory cycle alternate "1," "0" pattern and all "1's" and all "0's" patterns were run. The amplifier had good stability and could tolerate $\pm$ 5 percent voltage variations on the +24-volt supply and $\pm$10 percent variations on the -12 supply without slipping bits or triggering on noise. Pictures of the signal and noise (Figure 29a) were taken at the second stage of the Class A section and show the digit noise and signal with a ratio of about 8:1. The amplifier showed a total delay of less than 12 nsec, but wiring and circuit delays limited the total loop delay to 80 nsec. One problem that was observed was caused by the strobe pulse being over-peaked or under-peaked. Figures 29b and 29c show tunnel diode "1" and "0" patterns, and the diagram (Figure 30) shows how an over- or under-peaked strobe pulse can cause the tunnel diode to switch at a time when the signal is not present. Adjusting the input impedance of the current-steering circuit made possible a fairly flat pulse that allowed good operation of the amplifier. One reason for getting an over-peaked strobe pulse is base-to-emitter capacitance in the transistors plus wiring stray capacitance. A stray capacitance of as little as 1.0 pf can give an undesirable pulse shape. Very careful physical layout of the amplifier is necessary to reduce this problem.



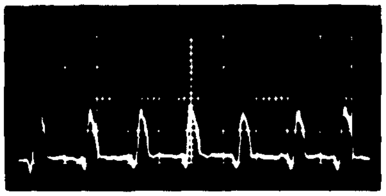
TIME ⟶

(a) Alternate "1," "0" Pattern
"A" Output



TIME ⟶

(b) Alternate "1," "0" Pattern
"B" Output



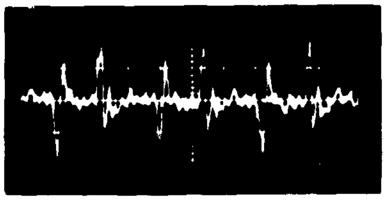
TIME ⟶

(c) "1's" Pattern
"A" Output

Vertical Calibration: 1 volt/div

Horizontal Calibration: 50 nsec/div

Figure 28. Waveforms of Sense Amplifier, "A" Output and "B" Output

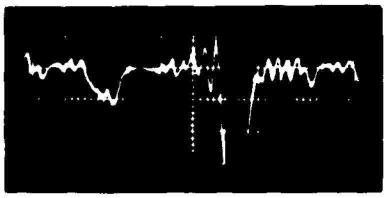


TIME ⟶

(a) Alternate "1," "0" Pattern
at Second Class "A" Stage

Vertical Calibration: 100 mv/div

Horizontal Calibration: 50 nsec/div



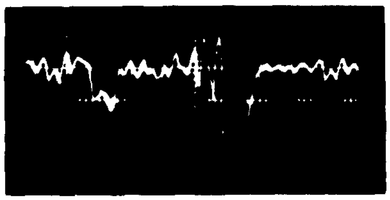
TIME ⟶

(b) Tunnel Diode "1," "0" Pattern
"A" Side

Vertical Calibration: 100 mv/div

Horizontal Calibration: 10 nsec/div

(c) Tunnel Diode "1," "0" Pattern
"B" Side

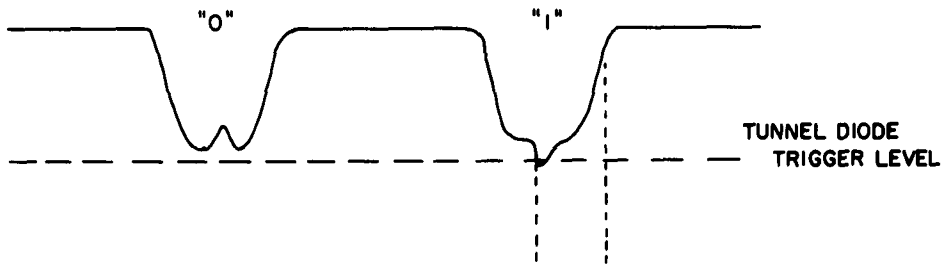


TIME ⟶

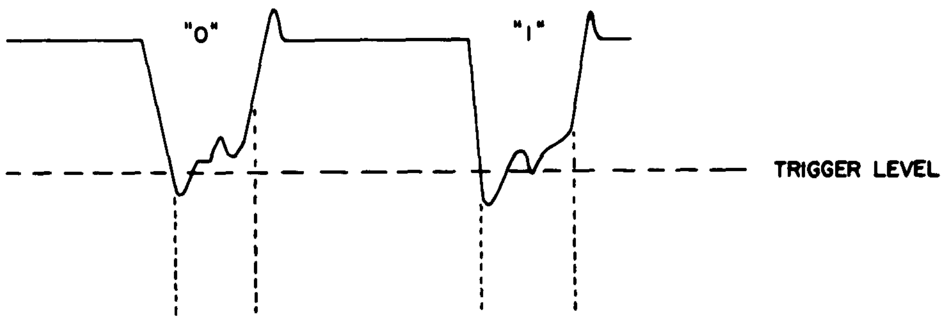
Vertical Calibration: 100 mv/div

Horizontal Calibration: 10 nsec/div

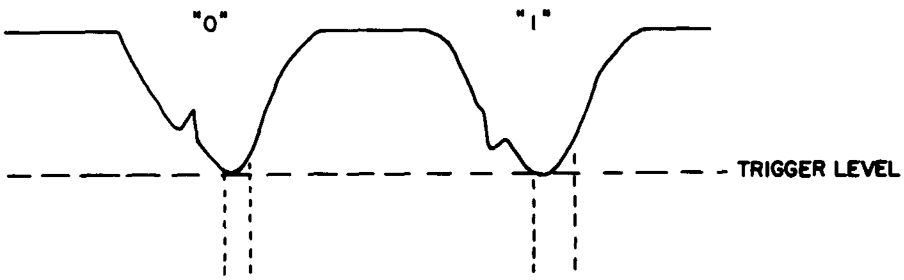
Figure 29. "1" and "0" Pattern at Second Class "A" Stage; Tunnel Diode "1" and "0" Pattern on "A" and "B" Sides



(a) Optimum Condition



(b) Over-Peaked



(c) Under-Peaked

Figure 30. Strobe Pulses

(4) CONCLUSION. This amplifier meets all the original specifications and should allow a 50-nsec memory cycle time if the other delay factors in the loop can be reduced. This amplifier is now being built in a package that can be plugged into the JDU where more tests will be run on the larger system. If this proves successful, this amplifier with few modifications should be usable in the LTM.

c. HIGH-LEVEL WORD TRANSLATION. During the last quarter, further work has been done on high-level word current translation. Lumped section transmission lines have been dropped in favor of distributed lines of higher characteristic impedance, which when periodically loaded with the capacity of the unselected transistors, have the desired 40-ohm characteristic impedance.

The case for 6 pf of loading every 5/8 inch along the line was calculated, and an electrical model of the line was built and tested. The calculated parameters were:

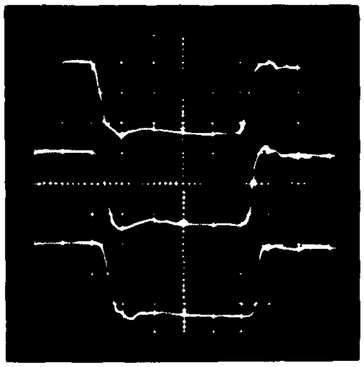
Z_0 of line before loading:	110 ohms
Z_0 of line with loading:	40 ohms
Delay time of loaded line:	0.486 nsec/inch
Delay of total line length:	4.86 nsec

The measured results were:

Z_0 of line with loading:	40 ohms
Delay of total line length:	2.9 nsec

Waveforms on the line are shown in Figures 31 and 32. Figures 31a, b, and c show the waveforms at the input end, middle, and terminating end of the line at 10-nsec scale division. Figures 32a, b, and c show the leading edge of the same waveforms at 2-nsec/ scale division.

Sneak currents on unselected word lines were experimentally investigated and found to be negligibly small, nearly non-existent.



(a) Input End

(b) Center of Line

(c) Terminating End

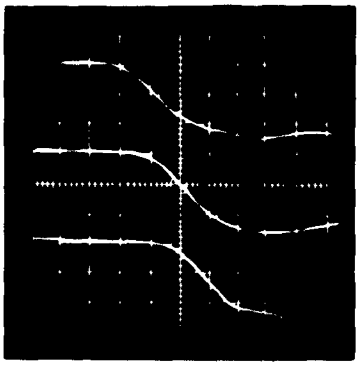
Vertical Calibration: 1 volt/div
Horizontal Calibration: 10 nsec/div

NOTE:

Line periodically loaded with 6 pf of capacity every 5/8 inch.

Figure 31. Waveforms of 10-Inch Model Transmission Line

Vertical Calibration: 1 volt/div
Horizontal Calibration: 2 nsec/div



(a) Input End

(b) Center of Line

(c) Terminating End

Figure 32. Leading Edge of Waveforms of Figure 31

Several new transistor types, just obtained, were evaluated for use in a drive circuit for the matrix selection lines. These units were found satisfactory, and preliminary design has begun on the drive circuit using these units. The schematic of the initial approach to a suitable drive circuit is shown in Figure 33.

The circuit consists of a current switch with a 3- or 4-way AND at the input, driving a complementary pair emitter-follower with an output impedance equal to the characteristic impedance of the selection lines (40 ohms).

A suitable diode was found to place in series with the base of the selection matrix transistors with a reverse bias junction capacity of about 1.5 pf ± 20 percent. The transmission lines will be redesigned around this value, rather than the 6 pf initially assumed. This modification will reduce the total line delay significantly.

d. FILM STRIPS. It was necessary to evaluate the film strips and the slit film strips for deterioration due to cross coupling and determine whether this deterioration was detrimental to the reliable operation of the strips as memory elements in the high-speed memory. The signal output from the strip was much larger than that from a round film spot, but because the "easy" direction of the rectangular strips was in the short dimension, there was some doubt as to the ability of the strip to act reliably. It was important to know how much the information stored in one particular cell would affect the information in the adjacent cell along the strip. A preliminary check indicated that the extent of a single cell's influence does not reach beyond its closest neighbors.

first pulse read out could not be observed directly, but when the green face plate of a Tektronix 585 oscilloscope was removed and No. 3000 film with the Polaroid camera was used, the single pulse output was photographed.

With the power supplies turned off, the digit line was biased momentarily at about 400 ma in the "0" direction to force the entire strip in the "0" state. Then, with the word line disconnected to help eliminate the effects of a transient on the word line and the digit driver set to supply a normal "0" bias, the power supplies were turned on with the mercury pulser still turned off. In Test 1 the word driver was connected to each word, the mercury pulser was single pulsed for each line, and the first pulse read out was recorded for all three cells. Then the center word line was pulsed about 10,000 times with the digit bias still in the "0" direction. In Test 2 the first pulse read out from the cells adjacent to the previously pulsed line was recorded. In Test 3 with the digit bias reversed to the "1" direction, the center line was again pulsed about 10,000 times and after returning the bias to the "0" direction, the first pulse read out of the adjacent cells was also recorded. For Test 4 the center word line was pulsed about 10,000 times in an alternate "1" - "0" pattern by closing the loop from the output of the sense amplifier to the digit driver. The digit bias was returned to the "0" direction, and the single pulse read out of the adjacent cells was recorded.

All the previous readout signals represented a small ($\approx 75°$) switch of the film. In Test 5 both polarities of the large ($\approx 105°$) switch were recorded for reference. The previous testing on the small switch indicated the worst deterioration in signal for the situation of pulsing the center word line in a state opposite to the stored state of the adjacent cells. Test 6 was made with the adjacent cells in the "0" state while the center cell was pulsed about 10,000 times in the "1" direction. Then the bias was left in the "1" direction and the large switch, first "0" pulse readout was recorded for adjacent cells.

Continuous Strips

Test 1 reference	1.2 divisions	
Test 2 pulse "0"	1.2 divisions	100% of 1
Test 3 pulse "1"	0.8 division	67% of 1
Test 4 pulse "1" - "0"	0.9 division	75% of 1
Test 5 reference	1.65 divisions	
Test 6 pulse "1"	1.45 divisions	85% of 5

It was noted during the tests that the magnitude of the signal from an alternate "1" - "0" pattern was about 50 percent of the signal from a continuous "1" or "0". When the pattern was switched from the alternating to continuous with a slow repetition rate (150 cps), a gradual buildup of signal was observed. From this it was concluded that the switching domain is normally small, probably over the intersection of the word and digit line, but continual pulsing in a single direction causes the domain to grow larger.

Because of the noted deterioration in the signal from the film strips for the various tests made, new film strips were made with 10-mil slits between adjacent cells. The resulting memory elements, 22 x 30 mils were tested with the same procedure and set up as the unslit film strips except that the word current pulse was increased to 500 ma.

Slit Strips

Test 1 reference	1.8 divisions	
Test 2 pulse "0"	1.8 divisions	100% of 1
Test 3 pulse "1"	1.5 divisions	83% of 1
Test 4 pulse "1" - "0"	1.6 divisions	89% of 1
Test 5 reference	2.8 divisions	
Test 6 pulse "1"	2.6 divisions	93% of 5

The deterioration for the slit strips is about half that for the plain strips, and the previously noted change in the magnitude of the output signal with a change in pattern, alternate "1" - "0" or continuous "1" or "0", was less than 10 percent. From these results and the fact that the high-speed memory with a nonreturn to zero uses only the large ($\approx 105°$) switch to close the logic loop, it was concluded that although further testing is required in a large array, the slit strips should operate reliably as a memory element.

e. REPRODUCIBILITY OF ELECTROPLATED THIN FILMS. The task definition of the electroplated thin film investigation at UEC, Philadelphia, involves:

1) Studying the preparation of 20-mil film spots with reproducible properties.
2) Studying the preparation of films with low value of H_K if task 1) is completed.
3) Studying electroplating on thinner, less fragile substrates if time permits.

Nickel-iron films having a permalloy composition can be electrodeposited from an acid sulfate bath having the composition shown in Table 5. For this investigation 1000-A

TABLE 5. COMPOSITION OF ACID SULFATE BATH FOR ELECTRODEPOSITION

Material	Formula	Quantity (grams/liter)
Ferrous sulfate	$Fe\ SO_4.7H_2O$	7.00
Nickel (11) sulfate	$NiSO_4.6H_2O$	218.00
Sodium chloride	NaC1	9.70
Boric acid	H_3BO_3	25.00
Saccharin	$C_6H_4SO_2NHCO$	0.83
Triton CF-21	(Trademark of Rohm & Haas Co. Philadelphia, Pa.)	1.30

thick films were electrodeposited onto 3 x 3-inch glass substrates which had been previously coated with an evaporated film of 1000-A chromium and 300-A gold. The evaporation of the chromium-gold layer was necessary to provide a conductive substrate for electrodeposition. The electrodeposition was carried out in the presence of a uniform magnetic field of 30 oe.

A tapered strip transmission line hysteresis loop tester (described in the last report), using 35-kc drive, provided the B-H data reported here.

B-H data obtained from 20 electrodeposited Ni-Fe spots 20 mils in diameter are shown in Table 6. It will be noticed that the coercive force of these spots is fairly uniform but that the values of H_K are extremely high. B-H data obtained from another Ni-Fe film deposited in a similar manner, but etched into 50-mil spots gave values of H_C in agreement with those for the 20-mil spots, but the values of H_K were in the range of 3.5 to 5 oe.

Several Ni-Fe films 1000 A in thickness were deposited on four 3 x 3-inch glass substrates and the Lightning array of two 16 x 24 matrices etched from the center of the substrate. Measurements of the hysteresis loops of these areas are shown in Table 6.

Variations of H_C and H_K are no more than twice the repeatability accuracy of the measuring apparatus. Reproductions of typical B-H loops are shown in Figure 34.

TABLE 6. VARIATION OF B-H PARAMETERS OF SEVERAL 20-MIL SPOTS OF ELECTRODEPOSITED Ni-Fe

H_C (oe)	H_K (oe)	H_D (oe)
2.8	9.0	1.2
2.8	8.0	1.0
2.6	7.0	1.0
2.2	8.0	1.4
3.0	9.0	0.8
3.0	10.0	0.8
2.8	7.0	0.8
2.4	10.0	0.8
2.3	9.0	0.8
2.4	10.0	0.7
3.0	9.0	0.8
3.0	9.0	0.8
2.6	11.0	0.8
2.4	12.0	0.8
2.4	9.0	0.8
2.6	10.0	1.2
2.8	11.0	1.0
2.4	9.0	1.1
2.4	9.0	1.0
2.4	12.0	1.0

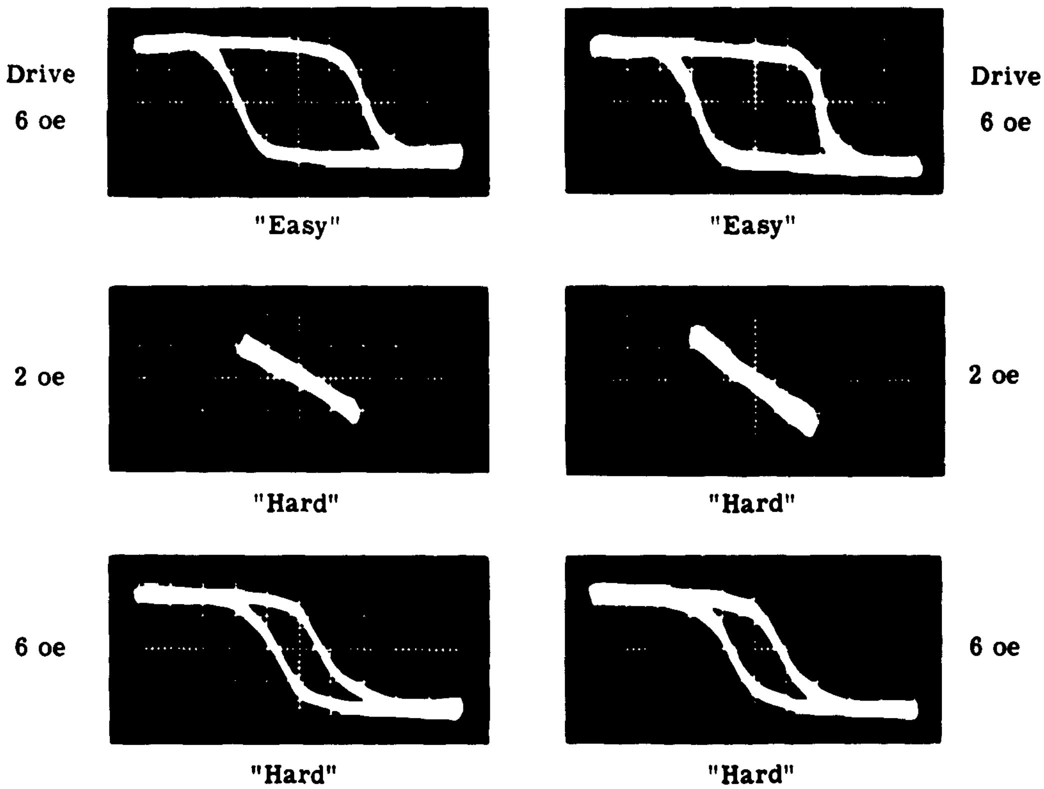


Figure 34. Typical B-H Loops

The use of a manual tester for testing Project Lightning film spots was abandoned. Attention was then focused on the use of printed circuit overlays to test film spots. Because of the opaque gold backing initial difficulty was encountered in registering the film spots to the printed circuits.

However, a 4 x 4 array of 20-mil spots was tested at St. Paul and, for spots tested, behaved in a normal manner. (The St. Paul Lightning array which is transparent was paired with the Philadelphia array so that alignment could be obtained.) The outputs were somewhat smaller than those of the St. Paul spots, but this was expected since the film was thinner than St. Paul spots (1000 A compared to 2000 A.)

The substrates measured for the data in Table 7 were all delivered to St. Paul. It is reported, informally, that they operate in a normal manner. Detailed pulse test data on these arrays are not available at the present time.

When a set of spots was used in conjunction with a continuous film and the thin three-layer circuit received from St. Paul, outputs of 4 mv were obtained. Small variations of the positioning of the spots relative to the wiring had very little effect on the output.

TABLE 7. B-H PROPERTIES OF 20-MIL SPOTS
ELECTRODEPOSITED NICKEL-IRON FILMS

Spot Address		Substrate No. P3-25-2			
		Section I		Section II	
X	Y	H_C (oe)	H_K (oe)	H_C (oe)	H_K (oe)
1	2	2.2	4.5	2.3	4.5
1	16	2.3	4.7	2.3	4.0
5	16	This part of the substrate broke during measurement		2.4	4.0
10	1			2.5	4.5
10	16			2.5	4.0
15	1			2.4	4.0
15	16			2.4	4.0
20	1			2.4	4.0
20	16			2.4	4.5
24	1			2.1	4.0
24	16			2.1	4.5
12	9			2.5	4.0
Average				2.4	4.2
				0.15	0.22

TABLE 7. B-H PROPERTIES OF 20-MIL SPOTS ELECTRODEPOSITED NICKEL-IRON FILMS (Cont.)

Spot Address X	Spot Address Y	Substrate No. P3-25-3 Section I H_C (oe)	Section I H_K (oe)	Section II H_C (oe)	Section II H_K (oe)
1	2	2.6	4.5	2.6	4.0
1	16	2.7	4.2	2.7	4.2
5	16	2.4	4.0	2.4	4.0
10	1	2.7	3.8	2.4	4.0
10	16	2.4	4.0	2.4	3.8
15	1	2.5	3.8	2.4	3.6
15	16	2.4	4.0	2.4	3.2
20	1	2.4	3.7	2.4	4.0
20	16	2.4	3.6	2.4	4.2
24	1	2.4	4.0	2.4	4.0
24	16	2.4	4.5	2.4	4.5
12	9	2.7	4.0	2.6	3.8
Average		2.5	4.0	2.5	4.0
		0.12	0.26	0.12	0.30

Spot Address X	Spot Address Y	Substrate No. P3-25-4 Section I H_C (oe)	Section I H_K (oe)	Section II H_C (oe)	Section II H_K (oe)
1	2	3.3	4.0	2.4	4.2
1	16	2.6	4.5	2.7	4.7
5	16	1.8	4.7	2.4	3.8
10	1	2.6	4.5	2.4	4.5
10	16	2.6	4.5	2.7	4.5
15	1	2.6	4.0	2.7	3.8
15	16	2.6	4.0	2.4	4.0
20	1	2.6	4.5	2.4	4.0
20	16	2.4	4.0	2.6	4.0
24	1	2.7	4.5	2.7	3.6
24	16	2.9	4.0	2.4	4.0
12	9	2.6	3.8	2.3	3.8
Average		2.6	4.2	2.5	4.0
		0.3	0.3	0.13	0.31

CONCLUSION. The first useful B-H loop measurements for a reproducibility study were obtained at the end of the work period. It is felt that poor registration of the film spots to the three-layer circuit was the principal difficulty in obtaining pulse test data. Also lack of measuring equipment limited the number of substrates measured during this period. That is, the small number measured is unrelated to the ability to produce the films or to their reproducibility.

There are positive indications that any electrodeposited films that give good reproducibility for 50-mil diameter circular spots, or any other shapes, will also be adequate for smaller sizes and shapes. Appropriate configurations and thickness would have to be used.